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SCIENCE TEACHING

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SCIENCE TEACHING

What it Was — What it Is —
What it Might Be

BY

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BLACKIE & SON LIMITED
LONDON AND GLASGOW
1929

Printed in Great Britain by Blackie & Son, Ltd., Glasgow

To

F. B. Stead

(H.M. Chief Inspector of Secondary Schools)

Colleague and Friend for Twenty Years

CRITICUS

" Illud ferre non possum. Tu, quum me incognito assentiri vetes, idque turpissimum esse dicas et plenissimum temeritatis, tantum tibi arroges, ut exponas disciplinam sapientiae, naturam rerum omnium evolvas, officia describas, quam vitam ingrediar, definias: idemque etiam disputandi et intelligendi iudicium dicas te et artificium traditurum: perficies, ut ego, ista innumerabilia complectens, nusquam labar? nihil opiner? Quae tandem ea est disciplina, ad quam me deducas, si ab hac abstraxeris? Vereor, ne subarroganter facias, si dixeris tuam. Atqui ita dicas necesse est."

AUCTOR

" Si qua videbuntur chartis tibi, lector, in istis
sive obscura nimis sive latina parum,
non meus est error: nocuit librarius illis
dum properat versus adnumerare tibi.
Quod si non illum sed me peccasse putabis,
tunc ego te credam cordis habere nihil.
'Ista tamen mala sunt.' Quasi nos manifesta negemus!
Haec mala sunt, sed tu non meliora facis."

PREFACE

A few years ago, a distinguished American educationist, who was on a visit to this country, told me that he had been reading an English book on the teaching of science, and it had seemed to him that the writer had been devoting his energies to forging thunderbolts for hurling at those who refused to subscribe to the whole of the articles of a curiously narrow pedagogical creed. He said that it reminded him of the methods of certain theologians in his own country, and he asked me if I myself had adopted any sort of stereotyped procedure for assessing the value of a lesson in science.

Thirty or thirty-five years ago, I might have felt a little uncertain of my answer.—When I first became a headmaster, and had to assess the value of the teaching skill of my staff, I adopted a scheme, common enough in those days amongst Training College masters of method (as they were called), of awarding marks for each of a certain number of selected points—class management, discipline, presentation of subject-matter, interest, lucidity, logic, form of questions, use of answers, success of experiments, use of experiments, use of experimental facts, use of hypotheses, method of establishing principles, general attitude towards theory, English, note-taking, and so on—and in that way I was able to make a rough estimate of a teacher's skill. The scheme seemed to work well enough in the case of teachers who taught on fairly orthodox lines, but, when I began work as an inspector, I soon discovered that the scheme not infrequently failed, successful teaching methods often differing radically. Sometimes a teacher would offend against almost every accepted Training College precept, and yet give a strikingly successful lesson.

Despite his entirely unconventional methods, he might have a gift of putting things so lucidly and in such an interesting manner, and his personality might be so dominating, that the boys would be simply carried away. The experienced critic soon finds it necessary to abandon all attempts at assessing values mechanically, though certain criteria will always be borne carefully in mind.

There is general agreement amongst those of us who have spent our lives as critics of teaching methods that the very last thing we desire to find in a teacher is that he has surrendered his own individuality and teaches in accordance with some other person's scheme of hard and fast rules.

Suppose that a teacher, who has to give a lesson on some particular topic, first forms in his own mind a perfectly clear and vivid picture of the subject, and then, in giving the lesson, succeeds by some means in transferring the picture to the minds of his pupils, who are then able to see it as clearly and vividly as the teacher himself does. Suppose, further, that we test the pupils and find that they have not only got hold of the facts but understand them perfectly. Even if that teacher's methods were entirely opposed to methods generally recognized, can we justly say that the teacher would have done better if he had set to work in a more orthodox way?

Perhaps the lesson has taken the form of a lecture. Some critics would then urge that although the pupils may have obtained a number of new facts, have understood the facts perfectly, and have made them a permanent possession, yet such a lesson is necessarily a failure because it has made no provision for a formal training, and that a particular—perhaps a unique—kind of formal training is the one claim that science can make for inclusion in the school curriculum.

But in making exclusive claims for science as a subject for training the mind, we are on very dangerous ground. Critics who will listen dispassionately to equally able specialist teachers giving lessons in, respectively, classics, mathematics, history, and science, will be forced to admit that, as far as mere intellectual training is concerned, it is exceedingly difficult to

assign a preferential award to any particular one. The only exclusive claim of science is that it is dealing with facts untinged with any sort of human prejudice (unfortunately, this does not apply to the hypotheses of science!): learners can thus be taught to form an objective judgment. But this very source of strength is also a source of weakness. A training in science can make no provision for an analysis of human motives or of any sort of emotional experience; and thus it does not prepare its learners to understand some of the greatest problems of life. And, after all, it is a people's literature, not their science, that depicts their character—their strivings and their failings, their laughter and their tears, and all those things that rouse to action.

The principal subjects taught in school are one and all intended to provide a mental training, each of them of its own kind, all in their way equally valuable. When it comes to a struggle with difficulties, the student of classics and the student of mathematics are at least as hard put to it as the student of science. The great claim of science for a place in the school curriculum is its provision of new knowledge, knowledge which is ever increasing, knowledge which is driving the world ahead, knowledge which it behoves every citizen to possess.

To urge this necessity for the dissemination of knowledge is not to underrate the value of teaching as an art. But the art of teaching cannot be analysed and reduced to rules. The art is the creation of a teacher as an artist, " varying with his gifts, fed by his knowledge, enriched by his qualities, expressing his own unique personality ". The teacher does not shape his material to his will, as an artist does who works in clay. He works on human lives which are themselves an active force in the process. Hence the art of teaching is more complex, more baffling, more elusive, than any other art, and none of us need feel ashamed that we are unable to reduce it to principles and state its canons.

But, if it is nothing else, the art of teaching is, at least in skilful hands, dynamic, intensive, even aggressive. The

mere pabulum the teacher uses for his purpose, science, literature, or what not, matters little. The teacher who understands his work will make his own subject intellectually exacting, be the subject what it may.

It has been seriously said that Britain might still retain her leading place amongst the nations of the world if all her rulers were men of science. Such a statement is only provocative of ribaldry. Would the penetration of such men into human motives be clearer? would their judgments be more impartial? would their ability to weigh evidence be greater? Nevertheless, it would be better for us all if our rulers had a deeper knowledge of science, if they more clearly understood its applications, and if they were thus able to give the people a clearer orientation of the social forces contributing to our environment and moulding the future. Indeed, our rulers ought to be equipped in such a way as to be able actually to discover such forces, and some knowledge of science and some training in scientific method are essential for such discernment.

A recognized leader of political thought recently described inoculation as unclean! A medical man recently giving evidence before a salaried judicial functionary said, " the woman had an aneurism in the sub-clavian artery ", a statement expressed in terms so simple and accurate as to be unexceptionable. But the medical man was promptly rebuked by the functionary for " indulging in scientific jargon "! Ill-informed politicians may still win for themselves a measure of esteem from the ill-informed sections of their constituents; ill-educated men may still be jockeyed into important official positions.

But an eminent man of science went a little too far when recently he said, " at present the policy of most states is framed by politicians, carried out by civil servants, and interpreted by journalists, all equally ignorant of science ". Of journalists, I have no knowledge. Politicians as a class certainly do seem to be ignorant of science, but in every party there are statesmen (Lord Balfour is one, Lord Haldane was another) whose wide and accurate knowledge of science commands respect.

As for civil servants, I happen to know that within their ranks is a large number of men with high scientific attainments. Whilst it is quite true that there is a general ignorance of science amongst the more responsible classes of the community, exaggerated statements from men of eminence are not likely to advance the cause that such men have so warmly at heart.

There can be no doubt that the science teacher's real battle is concerned at least as much with the dissemination of knowledge as with the training of the intellect. Science teachers must cease to look at their several subjects so much from the inside. They must try to appreciate the unity of purpose of the whole range of scientific study, and the impacts of this study upon the common stock of ideas. They must break with the bad tradition of serving up year after year the same twopenny-worth of weighing and measuring—that poor little miniature of a university dish, not even garnished to conceal the beggarly fare it contains. They must broaden the basis of their teaching, particularly by the inclusion of biology. They must extend their pupils' scientific horizon. They must give up the idea that, if they give a lesson on some small topic of science by methods which will win the warm approval of the doctrinaire critic, they are therefore discharging effectively their main function as science teachers. The teaching of science is a much bigger thing than the devising of means of giving satisfaction to critics of the minutiæ of laboratory procedure. A laboratory is not a place either for the mechanical repetitions of a cloistered cell or for the dusty ritual of an antiquary's den.

At present, biology receives such little attention that several chapters of the book are devoted to considering its possible developments in school science courses. No school will be able to find time for the whole of the work outlined, and any school which attempts anything like a complete biological course will probably be compelled to drop a good deal of the usual physics and chemistry, with the possible consequence

* For instance, three of my old colleagues at the Board of Education were Fellows of the Royal Society, and many others had obtained the highest distinction in science that their universities could offer them. And I believe it is a fact that science is not less well represented in the other Government departments.

of weakening foundations generally. Much will depend upon the amount of time that can be given up to science. The present neglect of biology is all the more lamentable seeing that there is now a world-wide recognition of the fundamental importance of an expert knowledge of plant physiology and plant pathology (to mention only one aspect of biology). Within the next few years there is likely to be a far greater demand for trained biologists than our schools and universities can possibly meet. Whose is the fault?

It is in the Sixth Form where new teaching experiments may be freely tried. By that time pupils will, presumably, have been well trained in essentials, especially in the essentials of scientific method, and teaching methods may then become much more varied and much freer. A good deal of attention has therefore been devoted, in later chapters, to possible Sixth Form work on new lines. The needs of the Higher Certificate examination have, of course, to be borne in mind, but, if science teachers will only agree amongst themselves as to the scope and extent that Sixth Form work might best assume, they will probably enlist the ready sympathy of examination authorities.

In some of the chapters dealing with subjects not often taught, rather more than mere running comments on methods have been given: a certain amount of subject-matter itself has been included, always in a condensed form, just enough to indicate what to look for in the textbooks and what general sequence to follow.

Any merit that this book may possess must be ascribed to the many hundreds of science teachers whose work I have been privileged to see. I have been present at something like 1000 lessons a year for over 30 years, and naturally there have been occasions when the lessons were not an unqualified success. Rarely, however, have I failed to discover in a lesson *something* worth remembering, and I hope that the results of this gleaning and garnering, as here presented, will help to make the work of beginners a little more fruitful.

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PART I

SOME PRINCIPLES OF SCIENCE TEACHING

The chapters of this section of the book refer mainly to methods—methods which are known to be sound and methods which are known to be otherwise.

CHAPTER I

The Teacher: his Knowledge and his Training

The Marks of a Successful Science Teacher

What are the marks of a successful science teacher?—He knows his own special subject through and through, he is widely read in other branches of science, he knows how to teach, he knows how to teach science,* he is able to express himself lucidly, he is skilful in manipulation, he is resourceful both at the demonstration table and in the laboratory, he is a logician to his finger-tips, he is something of a philosopher, and he is so far an historian that he can sit down with a crowd of boys and talk to them about the personal equations, the lives, and the work of such geniuses as Galileo, Newton, Faraday, and Darwin. More than all this, he is an enthusiast, full of faith in his own particular work.

He may have first-rate laboratories and equipment, a generous time-allowance, and an ideal syllabus, but, unless he really knows how to teach and is keen on his work, success will not come his way. On the other hand, if he is keen and well-informed, he may succeed in spite of discouragement and poor equipment.

It is the man that counts. All obstacles he pushes aside.

* I have differentiated between "teaching" and "the teaching of science". The book does not set out to give an exposition on the art of teaching in the broader sense. Nothing, for instance, is said about discipline, and very little about the art of questioning, or about a score other things that every teacher ought to know, whatever his subject may happen to be. There are at least half a dozen helpful handbooks dealing with all such points, and Ward and Roscoe's *Approach to Teaching*, the newest, is full of hints of the greatest value, both to beginners and to teachers of experience. It contains a final chapter of useful suggestions for a teacher's library.

Academic Knowledge

What academic knowledge may reasonably be expected from a science teacher? A Cambridge science degree admittedly stands first. There are advantages at Cambridge not to be had at any other university in the world. During four years there, a man * will have taken up three or four different subjects, specializing in one. At Oxford (where science is at last creeping ahead, though its taps on the door of the temple of the "Greats" are still too gentle to be heard within), most of the time will be devoted to a single subject. At London and the newer universities, one principal subject and one subsidiary subject are most likely to form the course taken up (it is assumed that the man is reading for an Honours degree). Is the knowledge thus acquired enough for teaching purposes?

Emphatically the answer is in the negative. The university courses have not been designed primarily for teachers but for science specialists—chemists, engineers, biologists, and others. The university provides no special training in scientific method; it assumes, rightly or wrongly, that that has been provided at school. The work done is of necessity largely technical, and in that sense travels beyond the boundaries of school work. A university rightly considers that one of its main functions is to prepare a man for the continued study of his subject throughout his life, to help him wrestle with the intellectual difficulties arising out of that particular branch of knowledge, and thus to teach him how to dig down to the foundations of any kindred branch of knowledge that in future may interest him.

On the other hand, much of the work which is necessary for schools is often not included in the course selected for a university degree. A degree may be taken, for instance, mainly in chemistry, and the man be wholly ignorant of biology and almost ignorant of physics. There are instances of men who have taken a "science" degree in mathematics, logic, and

* I apologize to science mistresses for adopting this unsatisfactory translation of *homo sapiens*.

psychology, and have never lighted a bunsen or handled a test-tube in their lives. There are other instances of men who as private students have taken a science degree in chemistry and physics and have spent less than six months in laboratory work. Graduates of these classes are seriously handicapped if they take up science teaching, for they have to settle down to a great deal of drudgery, rarely very fruitful in its results, in order to equip themselves adequately for the professional work they have taken in hand.

Admittedly the necessary approach to science in school is fundamentally different from that of the university. University teachers naturally assume that their students are capable of taking in " lectures " and do not require " lessons ": that theoretical courses and laboratory courses, though proceeding more or less collaterally, are not necessarily interrelated step by step as in schools. A young science master sometimes doles out to his boys the petrifying stuff from note-books compiled at his university lectures, with barren results as he soon discovers.

But the value of the highly specialized work done in university courses must not be underrated. Unless a science teacher has carefully examined both the foundations and the superstructure of at least one subject of science, and has wrestled with its real difficulties, his respect for his work is not likely to be great; and only then has he the legitimate right to sit side by side with the classical scholar and with the trained mathematician.

A science teacher can hardly claim to be well equipped for his work before the age of 30 or 35. The trifle that he reads during the three or four years at the university counts for something, but what he reads during the ten or fifteen years afterwards counts for very much more. A science teacher ought to know something, and know that something well, of every main branch of science; and at least a full year of leisure time must be given up to a new branch before its outlines can be mastered and before the foundations on which it rests can be fully examined.

Science teachers who have been reading science for thirty or more years have told me how sadly out of date they feel themselves to be because of the impossibility of keeping in touch with the ever-increasing advances in the subject. Men who have taken up classics, or modern languages, or history, or mathematics, are in a rather different position. At the university they covered much of the ground in their subject fairly exhaustively, and they have since been able to keep in touch with research and new knowledge. But science has become such a vast subject, and in its rapid development it so easily outstrips all other subjects, that in a period of three or four years it is hopeless to try to cope with more than a selected corner of it. The remainder must come later, though alas! the greater part of it is likely to remain a sealed book even to the elect.

It is not merely necessary to take up new subjects, but to broaden and deepen one's own special subject. Consider, for example, how relatively little ground in chemistry can be covered in a university course. Much subsequent time is necessary for following up its manifold new departures and its ramifications into industry, physiology, and agriculture. It is not that the teacher may require for his daily work in the lecture-room and laboratory a knowledge of recent research (though for present-day Sixth Form work a science teacher must be abreast of the times); it is rather that a stale teacher is an unenlightened teacher. A stale teacher may not hark back quite so far as the age of phlogiston, but he is ever in danger of using hypotheses that had for a time been provisionally pressed into service but have since been thrown on the rubbish heap.

When a teacher's knowledge of science is confined to that of his university course, he has no claim to be made head of his department. He is unable to organize the work of his department as a whole, to supervise the work of his younger colleagues, to advise on the teaching of other science subjects, or, in short, to do more than when he was an irresponsible junior.

There is no excuse whatever for ignorance of the bare fundamentals of the main branches of science. Some years ago a science mistress who had taken a First in Botany Finals and who was a first-rate microscopist was giving a lesson on the barometer to a middle form (she was working single-handed), and a child asked, " Why does the barometer read the same in the laboratory as in the playground, seeing that outside there is a much higher column of air on the mercury?" Within the hearing of an inspector the mistress replied, " That is one of those things that even the cleverest men of science have never been able to discover "! That such a teacher should have been given a degree at all is positively immoral. Her answer showed that she did not know the ABC of elementary science.

Let the botany teacher remember that he must have a sound knowledge of chemistry and of elementary physics; the chemistry teacher, a sound knowledge of physics; the physics teacher, a sound knowledge of mechanics and mathematics; the mathematics teacher, at least an elementary knowledge of the philosophical foundations of his subject.

In short: a university course in science is just a preparation for the serious reading of the years to come.

Training

Nobody denies that a medical man or an engineer must be trained, for each of them has to acquire a knowledge of an art based on definitely established scientific principles. When people deny that a teacher need be trained, do they mean that teaching is merely a labourer's job? Do they deny it the rank of an art with its own definitely established principles? Is there anything for a beginner to learn from the experienced successful teacher? If so, what? and how should he learn it?

If he is lucky enough to spend a year at a training college where the principal himself is a man of science and a recognized authority on science teaching, or where at least the head of the department has been able to obtain similar public

recognition, he will probably receive the best training possible. Failing that, a post-graduate student-teachership at one of the great secondary schools where the science teaching is of recognized excellence, where the headmaster and the science staff will give a warm welcome to the novice, is perhaps the best, especially if, during the latter half of the year, lectures at university training departments can be attended. Of the twenty most successful teachers I have known, eleven were untrained, five were trained at a training college, and four at secondary schools. But the eleven were exceptionally gifted men and women, the sort of people who would have succeeded in any walk of life, no matter what difficulties they encountered.

Science teachers who have successfully undertaken a certain amount of research as part of their university course have probably obtained a clearer insight into scientific method than they could have obtained from most courses of training college lectures. In any circumstances, a training in the principles of scientific method is an essential part of the training of all science teachers. Some knowledge of the history and philosophy of science is also indispensable. Such knowledge will enable teachers to assess more correctly the true value of science as an educational instrument; it will make them more severely critical of loose reasoning; it will provoke them to be more insistent on accuracy of thought in their pupils.

CHAPTER II

The Purpose of Science Teaching

The Specific Claims of Science

The two principal claims of science for inclusion in a school course are so well known as to be almost commonplace. In the first place, the claim is made that it affords an unrivalled intellectual training, and teaches the learner to reason from definitely ascertained facts and to form an objective judgment; in the second place, that by its discoveries science is now making such great contributions to the prosperity of the human race, and is adding so rapidly to the sum of our knowledge, that the minds of those who are unversed in at least its main principles are, if not half barren, certainly imperfectly cultivated.

But it is difficult to maintain the first claim as the claim of science exclusively. If properly taught, classics, mathematics, or history provides an intellectual training not inferior to that provided by science; and classics and history have this advantage over science, that they take account of motive and action. It is true that science takes account of the analogous relation, cause and effect, but this relation is a much simpler relation; and thus, for the purpose of searching out the connexion between marshalled arrays of facts, science has the advantage of comparative simplicity. But unless science includes within its scope some consideration of human relations and interests, its priority of claim as an educational instrument will not remain uncontested.

The Cultural Value of Science

Now that science enters so widely and so intimately into every department of life, especially in all questions relating to health and well-being, it is important that the community should have a general knowledge of its scope and aims, of the

mode in which it envisages and attacks its problems, and of scientific method generally. It is, however, beyond question that it should be a general knowledge on broad lines: a specialized training in some highly technical branch of science is neither necessary nor desirable. But the general knowledge must be an accurate knowledge, a closely reasoned-out knowledge, built up on a basis of undisputed facts.

As a means of culture, the history of scientific discovery opens up to the imagination great pictures of the work of great men, thereby placing science in the front rank of humanistic studies. A knowledge of the methods of observation and experiment in the different branches of science helps to develop a logical mind, a critical judgment, and a capacity for methodical organization; while a knowledge of the great questions with which science as a whole is concerned fosters the broad outlook which is essential for the successful solution of the problems of life.

Is our present science teaching designed to meet these ends? Is there not some confusion between instruction in science and instruction in scientific technique? Are we not tending to teach science for specialists instead of science for citizenship?

It may be urged that a change in the direction of making our school science courses more general will result in giving children a mere smattering of a subject. But are children being given more than a mere smattering now?

Assuredly any science course should not only train pupils to weigh and interpret observed experimental evidence, but should also make them acquainted with the broad outlines of great scientific principles, with the way in which these principles are exemplified in familiar phenomena, and with their applications to the service of man. The two things should be recognized, and school courses framed accordingly.

But the tendency of recent years has been to over-emphasize the formal training, and to attempt to propitiate caustic critics by making great sacrifices on the altar of weighing and measuring; in short, to underrate the value of work at the demonstration table.

There is a certain body of scientific knowledge and a certain number of scientific ideas with which everybody ought to be familiar. These ideas permeate the whole atmosphere of common thought at its higher levels, and provide the basis of most forms of human activity. Gifted men well versed in other branches of knowledge, when dealing with certain aspects of practical affairs, are apt, apparently from the sheer absence of a common standpoint, to remain incapable either of apprehending the train of reasoning adopted by scientific men, or of seeing the importance of certain classes of evidence which it is absolutely necessary to weigh before a course of action can be rightly decided upon.

The ritual of the laboratory must not be confused with the spirit of science. The spirit of science cannot be weighed and measured, even if weighing and measuring are necessary for tracking it down. It is not enough to track it down, it must be captured; and not infrequently it evades capture because the reason is lethargic and the imagination dull.

The bed-rock facts of science are, of course, of fundamental importance, but, as an introduction to the teaching of science, they are certainly rather unexciting to children. In the early stages, facts which are not given a background of interest repel rather than attract. A first-year school course, designed to give a grounding in elementary science, often consists of colourless and uninspiring data.

The Training Value of Science

That a formal training in the methods of science is necessary will be admitted by all, and this formal training must be exacting, otherwise it will be of no avail. But a thread of interest of some kind should always run through the earlier general courses of instruction. Sometimes that thread of interest may be historical, the teaching being directed, in some measure, to giving general ideas of the development of science in the service of mankind. The long and patient struggle associated with the great names in science, the long series of

lucky accidents, of bold hypotheses, of painstaking studies, the failures and the disappointments as well as the successes, are the materials with which the imagination of the pupil may be kindled. Treated in this way, a science course may leave on the pupil's mind a lasting and vivid picture of human endeavour, throwing light on the past and the present, and giving glimpses of possible achievements in the future.

But the formal training should have as its ultimate goal the making of "a cold logic engine", as Huxley phrased it: a training in observation, in the garnering of facts, in the sifting of evidence, in the framing of hypotheses, in the scrutiny of hypotheses in the light of new facts, in the training of the impersonal judgment; in short, the training will be an initiation into the whole procedure of making a methodical purposeful quest amongst a tangle of physical happenings. If a boy is properly trained, the desire for discriminating evidence will become a predominating factor in his mental outlook.

This training can be effected without making boys embryo chemists, or electrical engineers, or biologists; without following courses of work based on syllabuses of the type of those for university entrance examinations, syllabuses designed to serve as preliminary studies of a professional type, to be extended later. Such courses are too specialized and too limited. It is true that a small amount of very exact quantitative work may be done by a boy working for his school certificate, but at what a cost! He may be able to find the specific heat of a metal accurately to three places of decimals, to find the refractive index of a prism, to obtain wonderfully correct results in troublesome gravimetric and volumetric analyses; and yet he will probably have no idea how the distance of the sun was discovered, how a plant breathes, how animals are classified, or that his own body is the most perfect combustion engine in the world; and he will be just as ignorant of scores of other things about which every intelligent person ought to have a clear understanding. He probably does not know a tithe of the scientific words in common use, and more likely than not he is ignorant of the nature of many everyday

phenomena and of the applications of many common scientific principles. The literature of scientific subjects is probably almost as unintelligible to him as to boys who have never been taught science at all.

Formal Training *versus* Cultural Value

All down through the ages educators have quarrelled over this question: should the chief aim of education be formative or informational? mind-training or mind-filling? In the teaching of science there can be no doubt about the reply: both are equally necessary. Neither must be sacrificed to the other, neither given priority. Forty years ago, intellectual training had given place to the doling out of knowledge; then the pendulum swung violently back, and intellectual training was given an advocacy that soon made it paramount. Now the pendulum is swinging again in the opposite direction. The partisanship cannot be justified, and it is for science teachers to see that a proper balance is preserved.

Here is a suggestive extract from a recent letter to *Nature*. " While science has now illuminated the Western world for some hundred years, no bold attempt has yet been made to reorganize and direct our social system in keeping with it. It has been given no cultural value, although it has had a profound and disturbing effect on all previous types of culture and æsthetic ideals. The coming of science and industry has completely changed the world. It has given us social, economic, and international problems which cry aloud for scientific solutions, but unless the mass of people is trained in the atmosphere of science, it will persist in attempting to solve these problems on traditional mediæval lines."—This is an accurate reflection of the opinion of many thoughtful men, and every science teacher should see to it that he does his share towards solving the very difficult problem of giving science an adequate cultural value as well as making it a subject for training the mind.

CHAPTER III

Methods

Methods of By-gone Ages

Are our methods of teaching superior to the methods of such teachers of by-gone ages as Plato and Aristotle?

Plato and his pupil Aristotle are the great exemplars of the two contrasted teaching methods that have always divided schoolmasters into two camps. Plato's method was to dig into his own mind for first principles, submit these to the most drastic criticism, and then to build up a system upon them as foundations. His method was wholly deductive. His famous pupil Aristotle broke away from this method and called for *facts*. Aristotle's method was essentially inductive. His foundations were facts about which people were in general agreement. He profoundly distrusted Plato's apriorism, yet, curiously enough, he often violated his own rules.

Plato's main interest was in man, rather than in nature in the wider sense. Aristotle's interests were more comprehensive. True, Aristotle was as keen a student of man as Plato was, but he took the whole of nature for his province. In criticizing Aristotle, we must bear in mind that in his time experimentation was in its infancy. Such experiments as were attempted were necessarily crude. Of apparatus there was really none, and of methods of scientific investigation there were no established principles at all.

Some 2000 years later, another great exponent of the inductive method arose, an Englishman, Francis Bacon. He laid it down as a fundamentally necessary thing that progress in knowledge depended on the accumulation of *facts*, a sifting of the facts, an organization of the facts, and a search for similarities and differences. Aristotle and Bacon were the two first great advocates of the method which it behoves all students and teachers of science to follow. It is true that Bacon, like

Aristotle, often broke his own rules, but it is hardly surprising that he was occasionally enmeshed in the traditional systems of mediævalism.

But Plato's method also plays a part in science teaching, a more important part than is commonly admitted. It was Plato's custom to ask his pupils these questions: State what you really know about this thing; give an exact explanation of every term you use in your description; how do you know that your statements are true? on what principles is your reasoning based? how did you ascertain the truth of those principles? how did you reason out your conclusion?—Surely this is a model form of questionnaire for every science teacher, to apply both to himself and to his pupils.

Plato was a ruthless critic of other people's conclusions. He would almost always catch his disciples tripping somewhere. Even his most brilliant students would sometimes use a word in slightly different senses, and that difference would inevitably lead to a student's discomfiture. Aristotle set to work in an entirely different way. He called for observation and experiment, for facts, and still more facts; now organize your facts, he said; what inference can you draw from that array of facts? are you quite certain that the inference is justified?

So it was with Bacon.

Science teachers may learn much from both Aristotle and Plato; so may science examiners.

Science Teaching from 1867

Down to the middle of the nineteenth century, science was the veritable Cinderella of the British school curriculum. Science itself was making headway, but science teachers were few, and those few were engaged in fighting down opposition all round. Canon Wilson,* afterwards Headmaster of Clifton, was the recognized protagonist, and in 1867 he rang up the curtain on modern science teaching. We may quote from his book:

* Canon Wilson is still with us, apparently as intellectually alert as ever.

"Science is the best teacher of accurate, acute, and exhaustive observation of what is; it encourages the habit of mind which will rest on nothing but what is true; truth is the ultimate and only object, and there is the ever-recurring appeal to facts as the test of truth."

"Science teaches what evidence is, what proof is."

"It is important to distinguish between *scientific information* and *training in science.* Both of these are valuable, but the scientific habit of mind, which is the principal benefit resulting from scientific training, can better be attained by a thorough knowledge of the facts and principles of one science than by a general acquaintance with many."

"The lecture may be very clear and good; and this will be an attractive and not difficult method of teaching, and will meet most of the requirements. It fails, however, in one. The boy is helped over all the difficulties; he is never brought face to face with nature and her problems; what cost the world centuries of thought is told him in a minute; his attention, understanding, and memory are all exercised; but the one power which the study of physical science ought pre-eminently to exercise, the power of bringing the mind into contact with facts, of seizing their relations, of eliminating the irrelevant by experiment and comparison, of groping after ideas and testing them by their adequacy—in a word, of exercising all the active faculties which are required for an investigation in any matter—these may lie dormant in the class while the most learned lecturer experiments with facility and explains with clearness."

"A master who is teaching a class quite unfamiliar with scientific method, ought to make his class teach themselves, by thinking out the subject of the lecture with them, taking up their suggestions and illustrations and criticizing them, hunting them down, and proving a suggestion barren or an illustration inept."

All this reads as if written in 1928 instead of more than sixty years ago. Canon Wilson's advocacy soon began to bear

fruit. Some progress in providing facilities for practical work was made even in the seventies; in the eighties, laboratories —of sorts—began to multiply; but until the early nineties progress in this direction was slow.

Every now and then a new educational prophet arises. He tells us that everything is wrong, and that he alone possesses the key for putting everything right. Those of us who have watched the rise and fall of many prophets are driven to the conclusion that real progress in *methods* is a thing of exceedingly slow growth, and that it is stupidly false to assert that present-day methods are conspicuously more successful than the methods of a generation or two ago. And, after all, it is not so much the method that counts as the man.

Nevertheless, the methods of science teaching have undoubtedly improved in some measure.

The Methods of Forty Years Ago

Forty years ago, there were few school laboratories available, and these were usually poorly equipped, and such science teaching as was done was usually done at the demonstration table; but even for this work the equipment provided was generally meagre in the extreme.

In those days, as now, a certain number of science teachers gave " lectures " to their classes, sometimes using their own lecture-notes of college days. And in those days, as now, such lectures were wholly ineffective. " Lectures " to university students are, of course, the normal thing, and lectures to a Sixth Form are often quite appropriate: students of trained intelligence want something to bite at. But lectures to younger boys are out of place, a principle which was as fully recognized by the majority of teachers forty years ago as by teachers of the present day. Most teachers of that time really *taught;* they did not merely talk; and more often than not the boys were remarkably keen on their science lessons. At each step of the demonstration, they had to describe in accurate language what had been done, and they were there-

fore compelled to observe carefully; then they had to say what might be inferred, and the discussions concerning the false inferences which pupils often drew were not infrequently of great value. Lastly, the results of a series of experiments were sometimes happily collated, and some point of theory worked out. Many of the pioneers of those days were really clever teachers and fully deserved the reputations they enjoyed.

Of course there were exceptions. I had my own first lesson in chemistry at the age of ten. We had no laboratory of any kind, but we did have a well-equipped demonstration table, and a plentiful supply of reagents, and the subject was taken by the visiting borough analyst. The first lesson of all—how well I remember it—was (of course!) on hydrogen, and lasted an hour. After spending a quarter of an hour on the preparation of the gas and a demonstration of its properties, the lecturer developed the atomic theory, and it is quite certain that he would have included large doses of isotopes and electrons if he had ever heard of them. Naturally the whole thing was a failure. But, then, teaching was not his professional work. For aught I know he would have added still further to his income by taking on, with the same royal confidence, an operation in surgery.

Such practical work as was done by pupils themselves in those days was almost always confined to chemistry, and to one small corner of that, namely, qualitative analysis, " test-tubing ", as some unkind critic has called it. Certainly the work was often unintelligently done. The teacher provided analytical tables, and a laboratory boy kept a Kipp in going order and the working-bench shelves stocked with the usual two dozen bottles of ordinary reagents, in addition to the few special reagents less frequently wanted. Nearly everything else was left to the pupils' own inner light, and they soon got into the habit of just saying, " Yellow: that's cadmium "; and so on.

But sometimes the work was so well done as to be of very substantial value. A preliminary discussion on solubilities

would lead to a boy's discovering for himself how to detect and then how to separate silver and mercury in a mixture of salts of those metals, then how to separate any two members of the first group, then how to construct a complete separation table for that group. By that time a boy began to realize the inner significance of the separation tables, and the work thereafter proceeded intelligently.

The same work was sometimes happily associated with the systematic study of the common metals, at the demonstration table, often with valuable results. And sometimes it was associated with the elementary study of pigments, an interesting development too often overlooked nowadays. Still, it must be admitted that qualitative analysis was given too prominent a place; it became too elaborated, and much practice made it wholly mechanical; tricky mixtures were given in examinations that demanded an entirely disproportionate amount of time for previous laboratory practice, and all other forms of practical work were neglected. Physics received little or no attention, and thus much of the experimental work in chemistry was not understood. But qualitative analysis *may* be made a valuable adjunct to any course in chemistry.

When I began teaching in 1886, I was given the opportunity, rather reluctantly, to give two lessons a week in chemistry, as well as the regulation two lessons in mechanics. There was no laboratory and no fitted demonstration table. The only balance available was a home-made one costing about 3*s*. 6*d*., with scraps of metal for the smaller weights. It weighed fairly accurately to one decimal place. The apparatus in stock was worth perhaps £2, and we were quite proud of our bunsen burner attached by rubber tubing to the gas pendant above our heads. I had discovered a book by an American professor, Ira Remsen, a revelation as to method in those days. In the middle of a lesson on equivalents, two visitors whose names I did not catch were shown in, and they sat down and listened. When I had finished they came up and showed what I thought to be a surprising appreciation of what I had been doing, and eventually one of them said: "Do you happen to know

Roscoe's book on chemistry?" "Yes," I replied, "and a thoroughly unsatisfactory book it is. The writer makes unjustifiable assumptions about chemical theory before he has established necessary facts. It is the kind of thing that no teacher ought to do." At this stage the second visitor interposed and said, "I think, perhaps, you are asking for trouble. Let me introduce you to Professor [afterwards Sir Henry] Roscoe." However, in spite of the criticized book, I learnt more about the teaching of chemistry in the next quarter of an hour than I might have learnt in the next ten years. In particular I learnt a much needed lesson—that there is more than one avenue of approach to the teaching of science, and that it is sheer folly to assume that science must be taught according to some particular pedagogue's prescription.

The advance in the forty years has not been in the direction of more telling work at the demonstration table, but in the direction of systematized laboratory training.

The "Heuristic" Method

Perhaps the most impatient man in the world of science teaching during the late eighties and the nineties was Dr. H. E. Armstrong, Professor of Chemistry at the City and Guilds Institute, South Kensington, still (1928) capable of hitting out as straight and hard as in 1888. Apparently the adolescent boys who were sent to him to learn chemistry were badly grounded in elementary science, and had little knowledge of any sort of methodical procedure; and he complained bitterly of the ineffective teaching in the schools whence they came. Thenceforward he became a strong advocate of a special type of laboratory training, and he revived the rather unfortunate term "heuristic" (εὑρίσκω = I discover), and thereby gave the philistines their opportunity. Had the word adopted suggested *search* instead of *discovery*, the philistines would have been disarmed.

Many years ago I asked a young science master, who talked a great deal about methods, if I might invite his classical

headmaster to be present at a first lesson on electricity. He assented readily, and the lesson was given. He had the usual stock (in those days) of glass rods, sticks of sealing-wax, ebonite, silk, flannel, and pith-ball and gold-leaf electroscopes, worked the usual experiments, and tabulated in two columns on the blackboard his differentiated results. So far, excellent. Then he began to get the boys to draw inferences, first telling them that they must not talk of two kinds of electricity but of two kinds of electrification. The boys' general conclusion, arrived at as a result of a string of leading questions from the teacher, questions which almost put into the boys' mouths the words the teacher wanted, were that like electrifications repel, unlike electrifications attract. The boys were then told that this was a " law ", and that they had " discovered " it. Naturally the headmaster, a particularly clear-headed man, pounced at once upon " such shoddy reasoning ". " All that you have done is to sort out the things you rubbed and the things you rubbed with into two classes (though even this distinction is not logically justified, for you rubbed the silk with the glass rod just as much as you rubbed the glass rod with the silk), and you sorted out the results according to the movements of the pith-ball; it was obvious that you were making use of previous knowledge, for you took care always to rub the glass rod with silk, and the sealing-wax with flannel. How then are you justified in saying that you have ' discovered ' that all substances are divisible into two groups producing opposite effects? And how can you say that there are two kinds of electrification? Why two kinds of electrification rather than two kinds of moonshine? Your classification of the experimental facts is not logical and your conclusions not justified. I know nothing of the subject but what I have learnt from your lesson, but it is obvious to me that your conclusion is not an inference at all, but an hypothesis, in other words a guess, put forward to ' explain ' your particular grouping of facts. And why did you use the words *attract* and *repel* to describe the movement of the pith-ball? You might have said that the pith-ball moved *as if* there were attraction and

repulsion, but there was no evidence whatever in your experiments to explain *why* the ball moved as it did. Surely at this stage you should have been content to describe, and not put forward an hypothesis which you cannot support. If this is what you call science teaching I prefer that the boys devote their time to some other subject."

The headmaster's pungent criticism was fully justified. The grouping of facts is a relatively simple matter. The "discovery" of the logical conclusion that may be drawn from such grouping is more often than not something entirely beyond the skill of the beginner.

There is thus a need to use the word "discovery" cautiously.

Professor Armstrong describes the (so-called) heuristic method thus:

"Heuristic methods of teaching are methods which involve our placing students as far as possible in the attitude of the discoverer—methods which involve their *finding out* instead of being merely told about things."

"The student is required to solve a number of problems experimentally: to determine, for example, the composition of air and water; and the idea of measurement is introduced from the very beginning, as the determination is made quantitatively as well as qualitatively. Each student receives a paper of instructions which are advisedly made as bare as possible so as to lead him to find out for himself or inquire how to set to work; he is particularly directed that, having made an experiment, he is to enter in his note-book an account of what he has done and of the result; and he is then and there to ask himself what bearing the result has upon the particular problem under consideration: having done so, he is to write down his conclusion. He is thus at once led to consider what each experiment teaches: in other words, to reason from observation."

All this is admirable advice. We now give one of his "papers of instructions":

"PROBLEM: TO DETERMINE THE COMPOSITION OF AIR

"N.B.—Be especially on your guard against drawing conclusions which are not justified by the result of the experiment; but, on the other hand, endeavour to extract as much information as possible from the experiment.

"1. Burn a piece of *dry* phosphorus in a confined volume of air, i.e. in a stout Florence flask closed by a caoutchouc stopper. Afterwards withdraw the stopper under water, again insert it when water ceases to enter, and measure the amount of water sucked in. Afterwards determine the capacity of the flask by filling it with water and measuring this water.

"N.B.—The first part of this experiment requires care and must be done under direction.

"2. Allow a stick of phosphorus lashed to a piece of stout wire to remain for some hours in contact with a known volume of air confined over water in a graduated cylinder. After noting the volume of the residual gas, introduce a burning taper or wooden splinter into it.

"N.B.—The residual gas is called *nitrogen*.

"3. Burn a piece of dry phosphorus in a current of air in a tube closely packed with asbestos. Weigh the tube, &c., before and after the experiment.

"4. Repeat experiment 2 with iron borings moistened with ammonium chloride solution. Preserve the residual gas.

"5. Suspend a magnet from one arm of a balance; having dipped it into finely divided iron, place weights in the opposite pan; when the balance is in equilibrium, set fire to the iron.

"6. Pass a current of dry air through a moderately heated tube containing copper. Weigh the tube before and after the experiment; note also the alteration in the appearance of the copper.

"7. Strongly heat in a *dry* test-tube the red substance obtained by heating mercury in contact with air. At intervals

* This is apparently the *first* problem of Professor Armstrong's chemistry course. "The second problem of the course: to determine the composition of water" (pp. 227–8). "Having studied air, water", &c. (p. 230, *Method of Teaching Chemistry*).

plunge a glowing splinter into the tube. Afterwards note the appearance of the sides of the tube. (Before performing this experiment, ask for directions.)

"N.B.—The gas obtained in this experiment is named *oxygen*.

"8. Heat a mixture of manganese dioxide and potassium chlorate in a dry test-tube; at intervals plunge a glowing splinter into the tube. This experiment is to acquaint you with an easy method of preparing oxygen in quantity.

"9. Prepare oxygen as in experiment 8 and add it to the nitrogen from experiment 4 in sufficient quantity to make up the bulk to that of the air taken for the latter experiment. Test the mixture with a burning taper or splinter.

"10. Dissolve copper in nitric acid and collect the escaping gas (nitric oxide); add some of it to oxygen and some of it to air.

"11. Fill a large flask provided with a well-fitting caoutchouc stopper and delivery tube with ordinary tap water and gradually heat the water to the boiling-point; collect the gas which is given off in a small cylinder and add nitric oxide to it. Also collect a sufficient quantity in a narrow graduated cylinder and treat it as in experiment 2."

Twenty-five years ago I saw this paper of instructions in use on several occasions. Never were the results quite satisfactory. For beginners the instructions are inadequate. Indeed, this is admitted: "the first part of the experiment must be done under direction"; "before performing this experiment, ask for directions". A dozen boys besieging a teacher with questions, while another dozen are busy making all sorts of experimental blunders, perhaps trying to lash a stick of phosphorus to a piece of wire, perhaps trying to "obtain" "the red substance" by heating mercury in contact with air, is a sight to see. Even with a small number of boys, the whole investigation takes half a term, with the time ordinarily available. Let it be assumed that the training in method may be an unqualified success; from the point of view of knowledge gained, the half-term's work is wholly inadequate. One general

complaint made by teachers in those days was that difficulties constantly arose because the chemistry course was not preceded by a course of elementary physics. The phrase " sucked in " in experiment 1 suggests that no such course was intended and that this seriously incorrect explanation of a physical happening may be accepted.

Apart, however, from details possibly open to criticism, is the general principle of the method sound? *Merely* from the point of view of training in method, the plan, in the hands of the exceptional teacher, works well with a very small number of boys, say four or five, where the teacher can be at the elbow of each throughout the lesson. *But how much does the pupil really discover for himself?* Who does the real thinking, teacher or pupil? Of course with such a small number of pupils a teacher would at each step tell each inquirer just enough, but no more, to enable him to proceed. But when a dozen pupils are all clamouring for help at the same time, how can answers to inquiries be well thought out? In fact the method presupposes a very small class and a gifted teacher.

On one occasion in those days, a brilliant young master, now one of our most distinguished chemists, who had been brought up in the heuristic school, gave his first lesson in my presence. His chief had said to me: " I have just appointed a man who really does believe he can make the heuristic method a success." For his first lesson he had hoped to have a class of about half a dozen boys, but to his amazement he found that he had to take forty. He made " the composition of water " the subject of his lesson, and he began by preparing in a variety of ways supplies of hydrogen and oxygen. Experimentally the lecture (it did not pretend to be anything else) was a tremendous success—flashes, flames, sparks, and explosions galore. Never were boys more interested. At the end I asked them what the lesson had been about, and one little urchin said: " *Fireworks*, sir." When I gently chided the master for surrendering his principles, he replied: " But I was scared out of my life at the prospect of facing that crowd of boys." He had rightly divined that discipline must be given priority over method.

Essentially, the heuristic method is intended to provide a training in *method*. Knowledge is a secondary consideration altogether. The method is formative rather than informational. Such training, if properly carried out, does cultivate painstaking and observant habits, and encourages intelligent and independent reasoning. It does bring home to boys clear notions of the nature of experimental evidence, and the boys do learn that answers to questions can often be obtained from experiments they can work for themselves.

On the other hand, progress is inordinately slow, even with exceptional teachers. Far too little ground is covered in a term. The work attempted is confined almost entirely to physics * and chemistry, and boys get a wrong idea of science as a whole, or, for that matter, of physics and chemistry as a whole. The succession of exercises is rarely planned to fit into a general scheme for building up a subject completely; bits of a subject are chosen just because they lend themselves best to the particular type of training. Time is wasted over experiments that are beyond the pupils' skill and ought to be performed by the teacher. The whole method tends to be spoilt by its background of false perspective.

Unless the term " discovery " is confined to just the final result that naturally follows from suggestions and leading questions made by the teacher, it had better not be used. A boy never " discovers " a principle, and it is doing him a disservice to let him think he does. Above all things, science teaching demands intellectual honesty.

At the same time, no system of science teaching is likely to be effective unless it is animated by a spirit of *search*, whether at the demonstration table or in the laboratory. The pupil ought to see that the work he is engaged in, or that his teacher is engaged in, is a problem, and a problem worth solving, not merely a laboratory " exercise ". The teacher should keep the pupil's mind in a state of tension; he should compel the pupil to follow up the details of an experiment, and to piece

* Physics as well as chemistry have been included in all school courses for many years.

the details together; but the pupil's own inference, if correct, will never contain more than was included in the experiment, save something drawn from his stock of old knowledge. If the conclusion contains something previously unknown, that something was in all probability provided, somehow and somewhen, by the teacher. A beginner in science may " discover " a test-tube hidden in a drawer, but he will rarely or never discover a principle lurking in a group of facts. The boy may be taught to experiment, to observe, to sort out, to record, and to do all those things unaided; and he may be taught to search for resemblances and differences; but the new thing, the unknown thing, has, as a rule, to be given him.

The attempt to teach science merely for the sake of the training it may afford has resulted in much ineffective work. Still, " the spirit of inquiry " should most certainly be encouraged, and should run through any course of science teaching. By all means get boys interested in common occurrences, and lead them to follow up clues as to possible causes. Boys love to solve puzzles, to unravel mysteries. Encourage them to devise experiments to test their own explanations of things they have observed. Make them keen inquirers. Encourage habits of independent thinking about evidence obtained first hand.*

* I have never had the privilege of hearing Professor Armstrong teach, but I have learnt from several of his old pupils a good deal about his methods, and I am driven to the conclusion that he has never told us in either his books or his lectures what the secret of his method is. And I doubt if he is really aware of his own secret, any more than Colburn the calculator was, or any other person with exceptional gifts. His secret is not to be found in the use of the balance, or in heuristics, but probably in his own personality—his rather tart impatience towards his students, his refusal to help them one iota more than is absolutely necessary, his amazingly clever and ever-ready questions to meet the needs of the moment, his resourcefulness under all experimental difficulties, his untiring help to his students, his rather " grumpy manner ", and his rare words of praise. Said one old student, " We didn't like him at all at first, but he was a clever teacher. We felt he could almost see the thoughts in our minds and tell exactly how much help we really wanted in order to overcome our difficulties. Of course we never discovered anything important ourselves. We got that from Professor Armstrong or from books. But I think most of us did learn to understand things pretty clearly."

I wonder if Professor Armstrong, during all his teaching experience, ever had to teach a class of really dull students? Doubtless he has had new students totally ignorant of science, perhaps clumsy and stupid when first turned on to experimental work. But a class of really unintelligent students? I doubt it. Certainly not if those of his old students with whom I am acquainted are any criterion. He would hardly call a beginner unintelligent for failing to obtain the "red substance" from mercury heated in contact with air!

Lecture-room and Laboratory

The heuristic method is supposed to be based exclusively on laboratory work, the lecture-room being abolished. Its exponents sometimes grudgingly make the concession that formal lessons at the demonstration table are occasionally required to supplant the laboratory work, to drive home facts, and to clarify things generally. In actual practice, all teachers give such lessons, knowing well that otherwise their pupils' knowledge will remain nebulous, and their ideas more nebulous still.

Suppose that the work at the demonstration table takes the place altogether of work in the laboratory. Suppose that the teacher does all the experimental work and the pupil does none. What then?

First of all, what is a "lecture-room"? The term is appropriate enough in a college; perhaps even in a school, for the Sixth Form. But for younger pupils lectures *qua* lectures are out of place. Such pupils cannot follow chains of reasoning. They must be given one point, or at most a few points, at a time, and these must be understood and known before further points are considered. The veriest tyro of a teacher knows this. But what is a "demonstration table" and what is a demonstrator? Properly speaking, a demonstrator is one who performs experiments to illustrate, to confirm, to verify facts and principles enunciated by the lecturer. The assembled students listen, observe, and make notes. Formally they are not "taught". They are not examined or cross-examined. If they do not digest the fare provided, that is their look-out.

But in a school the lecture-room is a place for *teaching*, and the demonstration table is the teacher's laboratory bench. The teacher works experiments, often because the experiments are beyond the pupils' skill; the lesson consists of questions and answers all the time—directed questions, and in case of emergency leading questions, and answers which are used for cross-examination and for further questions. The teacher does not work experiments primarily to verify, but to present new

facts; and such facts thus presented at first hand are made the basis of the whole lesson. It is true that the pupils are not using their hands, but it is this freedom that enables them to give all their attention to the teacher; their attention is not divided by their having to engage in difficulties of manipulation. (It is, of course, assumed that the teacher is able to compel sustained attention.)

Who shall say that such a method may not be effective?

Suppose that a teacher plans out a course of work in a subject, then makes out a list of all the experiments he considers necessary for establishing facts and principles, ticks off those experiments which can safely be left for the pupils to do, and decides to reserve the rest to be done by himself at the demonstration table. Who shall criticize him for such a division of labour?

The success of present-day science teaching in this country —and much of it is undoubtedly successful—is probably largely due to a happy combination of demonstration-table and laboratory training. The Germans are not great believers in laboratory training for pupils (at all events *were* not, in pre-war days); they argue that it is wise policy not to give the pupils an opportunity of making mistakes. The Americans, on the other hand, tend to pin their faith to laboratory methods, methods which are, however, more strictly inductive than they are " heuristic ". Americans, including Canadians, have devoted an enormous amount of attention to methods of teaching, and it is doubtful if they have very much to learn from us. Their prepared " instructions " for pupils' laboratory work are often remarkably good.

The Germans ascribe much of their national thoroughness to their system of science teaching by lectures. The Americans ascribe much of their national keenness to their system of laboratory training, essentially a training on inductive and problem-solving lines.

Lecture-room *versus* Laboratory

Attempts have been made in America to estimate the relative values of work done by the " lecture " method and the laboratory method. One plan consisted in preparing a course of work for two classes of pupils, the course being given to one class in the lecture-room, the pupils of this class doing no experimental work at all, and to the other class in the laboratory, the teacher in this case doing no experimental work at all but giving such individual help as might be wanted from time to time. The two classes were of about the same average age, and of about the same average ability. For the laboratory class, very detailed papers of instructions were prepared, and a copy given to each pupil in order that he might set to work with a minimum of help from the teacher. A copy of the same instructions was given to, and had to be followed out by, the teacher in the lecture-room. At the end of the course, an examination was held, the same for both classes. The result was in favour of the lecture; the pupils had clearer ideas of what they had been taught, and they remembered their facts better. Three months later, a second examination was held, the questions being different from those at the first examination. Neither the teachers nor the pupils had been warned of this second examination, so that there was no sort of special revision. This time the result was slightly in favour of the laboratory pupils, who remembered the details of the experiments better than did their competitors; the latter, however, still had rather clearer ideas of what the aims of the experiments had been. But the most interesting fact is this: that the next term the " lecture " pupils not only attacked new problems better than the " laboratory " pupils, but were actually more skilful in laboratory manipulation.

It is quite unsafe to draw any general inference from such an experiment. The data are too scanty, the factors involved too variable. The experiment might with advantage be repeated, other experiments with the same end in view be devised, and the results of the different experiments compared. It is evident,

however, that those who roundly condemn lessons given in the lecture-room should pause. If it can be shown that the lecture-room method is as good as the laboratory method, both as to training and as to knowledge imparted, a great saving of time might be effected in our science teaching.

But we must suspend judgment.

The Historical Method

Some science teachers are strong advocates of developing a subject, not by first establishing accepted principles but by following the order in which investigators all down through the ages have gradually worked out the subject from its early beginnings. It is urged that chemistry in particular lends itself well to this treatment, that it is highly instructive to let a boy see how one hypothesis after another has been overthrown in the light of new facts, and that only in this way does he ever learn to adjudicate the real worth of scientific theory. It is, of course, an excellent thing for a boy to form the habit of asking whether an hypothesis is adequately supported by facts, and thus to learn that he must never try to make his facts fit the hypothesis. And no doubt the gradual development of the atomic theory can be unfolded historically in a very illuminating way.

The method can be pursued either in the laboratory or in the lecture-room or in both. But it is by no means always easy, indeed not always possible, to repeat the experiments of early investigators. A more serious objection is the inevitably slow progress which results from the method. It simply does not pay to spend a whole lesson over, say, the phlogiston hypothesis. Moreover, fundamental principles are apt to be obscured both by experimental details and by incidents in the lives of former investigators, details and incidents that are not worth remembering.

But some subjects, especially those that do not lend themselves to experimental treatment, may be developed historically, and to great advantage. In what better way can astronomy be

taught to an upper form than by successively taking up the work of Ptolemy, Copernicus, Kepler, Galileo, Newton, Kirchhoff, and others? And if only a very limited amount of time can be devoted to geology, what better general outline can be found for a Sixth Form than in Geikie's *Geologists*? Then there is much to be said for developing the subject of mechanics historically. Two lessons a week for a term could be profitably spent over the work of Stevinus, Pascal, Kepler, and Newton; and in this way, as in no other, the foundations of mechanics are likely to be well and truly laid, especially if Mach's criticisms are taken to heart.

Well-known stories from the history of science, such as Archimedes and his bath, Newton's question why the moon does not fall as an apple falls, always appeal strongly to a boy, and may be made the means of arousing interest for wrestling with the difficulty of a new principle. And such a book as Sir Richard Gregory's *Discovery* ought to be read by every Sixth Form boy in every school, whether science is his special subject or not. It is full of good stuff, stuff with which every educated person ought to be familiar.

If the historical method is adopted, the general method of the history teacher must be followed. The boy must be taken back and immersed in the period under study, be made not only to live with the people of that time and in their environment, but also to understand the stage and state of knowledge of the time and what materials the investigator then had to work upon. What is the use of discussing Roger Bacon and his work unless a boy first understands something of the spirit of mediævalism—that any person who attempted to unravel nature's secrets must be a special emissary of Satan himself, and be punished accordingly.

On balance, it may be said that teaching in accordance with historical sequence is not to be recommended for subjects usually taught up to the Fifth Form—physics, chemistry, and biology.

The teaching of the history of science generally is quite another matter, and provision should always be made for it.

Huxley's Method

So far as I know, Huxley never taught in a school, but those of us who sat under him as a lecturer never hesitated to say *that he was the most brilliant teacher we had ever known.* His lucidity of exposition was extraordinary. As far back as 1869 he gave a course of lectures to young people at the Royal Institution, his subject being physiography. The lectures were afterwards printed in book form, and for more than a generation the book was regarded as a model of scientific method.

But this was before the days of school laboratories. The lectures were frankly *lectures*, illustrated by experiments. Huxley said: " It appeared to me to be plainly dictated by common sense that the teacher who wishes to lead his pupils to form a clear mental picture of the order which pervades the multiform and endlessly shifting phenomena of nature, should commence with the familiar facts of the scholar's daily experience; and that, from the firm ground of such experience, he should lead the beginner, step by step, to remoter objects and to the less readily comprehensible relations of things. I conceived that a vast amount of knowledge respecting natural phenomena and their interdependence, and even some practical experience of scientific method, could be conveyed, with all the precision of statement, which is what distinguishes science from common information. And I thought that my plan would not only yield results of value in themselves, but would facilitate the subsequent entrance of the learners into the portals of the special science."

Huxley began with the familiar phenomena of a local river basin, and showed that the muddy waters of the river, the hills between which it flows, the breezes which blew over it, are not isolated phenomena to be taken as understood because familiar; but that the application of the plainest and simplest processes of reasoning to any one of these phenomena suffices to show, lying behind it, a cause, which again suggests another; until, step by step, the conviction dawns upon the learner that, to attain even an elementary conception of what goes on in his

parish, he must know something about the universe. Thus Huxley worked out, in a most admirable way, the principles of what we should now call physical geography, all traceable to the elementary principles of physics, chemistry, biology, and elementary astronomy. Huxley's pupils were active and not merely passive listeners; they *learnt*. They could not but learn, for Huxley was a born teacher, and the machinery of his method counted for little. His method embodied, in its spirit and mode of presentation, the true principles of scientific method. His scheme was an ever ramifying logical development from facts already familiar to the learner.

The "Concentric" Method

This is less a method than a scheme of organization. It is exemplified in the late Professor Sylvanus Thompson's book on magnetism and electricity, in which the whole ground is covered twice, the first time in outline, simply and qualitatively; the second in greater detail, with elementary mathematical considerations and with some approach to general completeness. The principle is, of course, that, in school practice, a subject can seldom be begun and be given an exhaustive treatment as it proceeds. A first and simple presentation of a subject may, often with advantage, be given to boys of, say, 14, gaps filled in the following year, and perhaps further gaps a year or two later still. This applies particularly to the different branches of physics. In the case of chemistry, the subject may be so organized that going back to early work, except for revision purposes, is less necessary. It is all a question of what pupils are capable of assimilating at each stage of their course.

We give two illustrations of this grading principle.—Suppose that the subject to be taught is the *rainbow*. The whole of the necessary work might be divided into three distinct stages:

Stage 1.—Boys 12 to 14.—Work wholly observational. (The phenomenon being comparatively rare, there would be no objection to a particular class being given the first opportunity

that occurred for making actual observations outside the school.) From a whole class, under guidance, the following observations might be expected, written records afterwards being made: (*a*) the obvious conditions of occurrence—the rays of the sun shining on falling drops of rain; (*b*) the brilliant colours of the bow, and their order; (*c*) the reversed and fainter colours of the secondary bow (if the latter is visible); (*d*) the relatively dark sky between the bows; (*e*) the general faint illumination inside the primary and outside the secondary bow; (*f*) the bows apparently the arcs of concentric circles; (*g*) the position of the observer with respect to the sun and the bows; (*h*) (with the teacher's help) the height of the bow and the height of the sun. The angular diameter of each bow might perhaps also be roughly determined by the teacher, with the help of the quicker boys. The succeeding class-work would probably consist of (1) the making of written records by the boys; and (2) the determination of the fact that the arcs of the bows have their common centre on the line joining the sun to the eye of the observer.

Stage 2.—Boys 15 to 16.—The subject would be taken up again in connexion with the study of optical reflection and refraction. An artificial bow would be produced by experiment, and an explanation—based as far as possible on (*a*) the boys' previous recorded observations, (*b*) the work just done in connexion with reflection and refraction, and (*c*) the artificial bow—would be given of (1) the formation of the bow by refraction and reflection; (2) the fact that no two persons can see the same bow, since the position of the base of the cone changes with the position of the apex; and (3) the fact that a reflected bow seen in the water cannot be the " image " of the bow seen in the sky.

Stage 3.—Boys 17 to 18.—Simple theory of the bow, from a consideration of the principles of interference and the necessarily constant angular radius of each bow, primary and secondary (about 41° and 52°). The complete mathematical considerations will, naturally, be beyond the ordinary school course.

Or take the subject of *capillarity*. Here, again, no teacher would attempt to exhaust the subject at any one stage. While observations of common capillary phenomena ought to be made and recorded by quite young boys, theoretical considerations can be taken up only at later stages.

Stage 1.—Observational work in connexion with simple experiments: (1) experiments with sponge, blotting-paper, sugar, chalk, cotton wick, a piece of cane, &c.; (2) adhesion of water to glass—effects studied before and after glass is polished; (3) capillary elevation and depression—plates and tubes; (4) study of "drops"; (5) experiments with soap bubbles; (6) study of plane soap-films; (7) liquid "skins"; (8) experimental illustrations (by the teacher) of the mode of formation of liquid figures by the principle of least superficial area.

Stage 2.—Study of surface tension and pressure; curvature of surface; angle of contact.

Stage 3.—Simple mathematical considerations. (Here, again, the complete mathematical theory is beyond a school course.)

Present-day Tendencies

Interesting experiments have become common in the teaching of experimental science to boys of about 12 by beginning the subject, not in the orthodox way of establishing principles step by step, but by handing over to a class a piece of mechanism,* it may be a bicycle, or perhaps an electric bell, telling the boys to discover everything about it they can, to consult people and to consult books, and to come prepared a week or so later to discuss the whole thing with their teacher. Each boy is able to contribute *something* to the common stock of facts, and a few boys will probably contribute much. For sorting out and arranging the facts, suggestions from the boys are called for; and a series of lessons are then arranged for working out principles, the known facts being supplemented

* See p. 82

by others derived from experiments which are worked either in the laboratory or at the demonstration table. In its way, it is the heuristic method over again, but there is no pretence that the boy is going to " discover " very much. He may discover *how* the thing works, but most of the *why* will be left to the teacher, and certainly the principles behind the how and the why will be mainly the business of the teacher. One great advantage of such a scheme for young boys is that they are really interested in the business in hand. And even older boys immediately show a keen interest when given an opportunity to investigate, say, the working of a fiddle, or a kaleidoscope, or a pump, or perhaps the working of a reciprocating engine, or an internal-combustion engine, or a dynamo. The subsequent serious work is understood and enjoyed much more than it would be if the subject were begun in the orthodox way. And the more that young boys are given a chance to make things, especially things that will " work ", the more real do such subjects as mechanics and physics become to them.

In America, the " topic " method finds great favour. A topic is announced, and the pupils are asked to say what they already know about it. In the discussion that follows, questions are bound to arise that no member of the class can answer, and these are jotted down for investigation. Suppose that the topic is *air*. The class will suggest a score of things at once: winds, ventilation, breathing, combustion, the diving-bell, the barometer, the pump, the airplane, the composition of air, liquid air, compressed air, and so forth. Clearly there is half a term's work here on the physics and chemistry of air, even when it is decided to postpone certain features that at the moment are too difficult. A course is organized accordingly, and the boys feel that it is *their* course. Or perhaps the topic chosen is the artificial lighting of the school; the suggestions made may include visits to the local generating station, to investigate the generation, transmission, and distribution of the current; the wiring of the school, lamps, meters and measurement, switches, fuses, and so forth. The immediate

fruit of these suggestions is an organized course in current electricity. But it is a great thing for the boys to feel that it is *their* course, and not a course thrust upon them by authority.

The plan is not so much a method of teaching as a method of approach to a subject. As always, the teacher himself is the man at the wheel, but the boys love to think that the ship would founder were it not for what *they* do.

This American system is said to work well. Boys are encouraged to consult books and read up the subject in hand; and in every lesson in classroom and laboratory fruitful contributions are, it is said, often made by the boys. The boys ask questions for the teacher to answer; the teacher asks questions for the boys to answer—it may be at the next lesson. Clearly the method has possibilities. The final aim is, of course, to work out main principles from accumulated facts, rather than to make the facts illustrate principles already established.

General Remarks on Method

Whatever general method is adopted, in detail it should as far as possible be consistently inductive. Begin with facts, facts which are already the common stock of the pupils, then with further facts obtained whenever possible from experiments, whether these are performed by the teacher or by the pupils. The next step will be generalizations from the facts. Thus far the work is merely foundational. As soon as the first hypothesis is put forward by way of some necessary explanation, a teacher's real trouble begins, for then both he and his pupils are sailing away into cloudland.

But remember that the inductive method may break down. Inductions by beginners are necessarily rather wild. Nothing is more common than faulty inductions, and the inductive method will inevitably betray the unskilled teacher. The discovery of a general law is sometimes the result of an inspiration, sometimes the result of a guess, rarely the result of logical analysis; and such discovery is hardly reducible to principles that can be taught. At all events the necessary teaching requires

great skill. Inductions can often be illustrated and verified by experiment, but the logic of the laboratory is generally spurious stuff. Any sound reasoning is likely to be the teacher's own.

Remember the inevitable danger of lectures. A preacher is supposed to be a teacher, but sermons are proverbially narcotic. It takes a Huxley or a Tyndall to lecture and keep the listeners' minds in a state of tension. Above all things let your method be such as to compel your pupils to think and to reason. Let your method be logical. Let the facts and the hypotheses which link them be set and seen in a clear picture—a puzzle picture in which the boys see exactly how the pieces fit together.

Beware of the pseudo method of discovery. "Pour H_2SO_4 on granulated zinc, and you will discover that hydrogen is given off"!

Beware of verification methods. "Show that ferrous ammonium sulphate contains one-seventh of its own weight of iron." This is simply asking for the evidence to be cooked.

When a boy works an experiment, keep him just enough in the dark as to the probable outcome of the experiment, just enough in the attitude of a discoverer, to leave him unprejudiced in his observations.

Do not adopt the heuristic extremist's principle that a pupil must not be permitted to take anything second hand. Life is too short.

Do not make the fatal mistake of thinking that all boys have an instinct and imagination for making discoveries, or can be made first-class workers in the laboratory. In any average science class, be satisfied with 25 per cent of α's, 50 per cent of β's, and 25 per cent of γ's, but do not stick labels on the γ's for all the world to recognize them.

Teach boys the virtue of recording all mistakes as well as successful results. Tell them that *all* science workers make mistakes: that that is almost the normal thing! Faraday, the most resourceful experimenter that the world has ever seen, said that he learnt far more from his mistakes than from his successes. A boy's laboratory note-book containing no mis-

takes is never a true record of the work he has done, and it is morally wrong to let it be presented as if it were such a record.

The pupil's notes should tell a plain tale to people who were not present when the record was made, and they should be written up in the laboratory, in ink, when the work is in progress.

In the laboratory, a teacher should have everything in readiness before a lesson is due to begin, including instructions as to the procedure to be followed in all experiments to be performed. If these instructions are given orally, they are forgotten; dictated, they take up much time; written on the blackboard, they are not permanent, and have to be written up again for a future lesson. Typed instructions answer best.

Whatever general method of teaching you adopt, do everything possible to economize time. It is bad economy—it is worse, it is sheer waste of time, to say nothing of a lack of ordinary teaching intelligence—to worry beginners about, say, the difference between density and specific gravity, or " pressure at a point ", or the number of stamens in a flower.

When devising methods for yourself, remember that good method can result only from the constant observation of certain broad principles. These include orderly procedure throughout a lesson, throughout the work of a term, throughout the whole course of instruction; an arrangement of subject-matter by which a waste of time and energy may be avoided; a distribution of emphasis which will secure the greatest co-operation from the pupils and maintain their active interest. But do not think that method can be worked out into a body of fixed and stereotyped rules of procedure, each applicable to its appropriate subject, as a kind of ritual to be observed by all teachers in all circumstances. Claims that this can be done may be rightly scorned. Teachers are not machines, to be turned by a handle.

At the end of each school year, let every science teacher under 35 take stock of the progress he has made in methods since his last stock-taking. Let him put his conclusions on paper, analyse them, and note down for future use any new

basic teaching principles, and any material which will strengthen principles previously formulated. In this way let him build up his own professional doctrine. The annual progress thus recorded may not greatly count unto him for righteousness, but at least it ought to count to his professional satisfaction, and to provide him with a defensive armour against destructive critics, should these ever assail him.

CHAPTER IV

Self-training

Hints to the Beginner

If you have not been trained but are lucky enough to obtain a first post as a junior, in a school with a large science department, under an efficient and experienced senior, all may be well. If you are unlucky enough to obtain a post where you have to work single-handed, your experience during the first year or two will almost certainly be purchased at the expense of your pupils. It is only fair to them, and it is greatly in your own interest, that you should obtain permission to visit two or three schools where well-known science teachers are at work, to observe, to ask questions, to make notes. Happily, there is amongst science teachers a camaraderie which all beginners should take immediate measures to share. If you are in or near London, attend lectures on method at the London Day Training College whenever possible. Make friends with Professor Nunn, and when in doubt or difficulty, ask his advice. Also make friends with the many clever people on the Science Masters' Association, or the Association of Women Science Teachers; they will always be willing to help you. Become an active member of one of those associations. Read *The School Science Review* regularly; every number contains

useful articles written by teachers who really know their business. Obtain permission from the Board of Education to attend one or two summer courses in science teaching; the time so spent will be of the greatest possible help. Then there is the question of reading. What books can you most profitably read, to help in your self-training?

Books to Read and How to Read Them

The ordinary standard works of science will help but little. These you will, presumably, have read already. The books to be read now are those which will help you to learn to teach. Of these there are two kinds which will help you much: (1) school-books written by prominent science teachers; (2) original records of the researches of great men of science. Books of the first kind should be read right through, not so much for the particular sections or particular lessons they contain, as for the authors' general method of approaching and tackling their subjects from the teaching point of view. Read one book through and try to catch the spirit of the author's method. Then read a book by a second author, then one by a third, and so on. Now compare and contrast the different methods. They are bound to be different, though perhaps all are excellent. Try to learn something from each, then sit down and try to evolve a general method of your own. Do not copy other people's methods. If you adopt a general method which you have not worked out for yourself, label yourself "second class" straight away. Let your general method of teaching be your own child, to be nurtured on the best brain-food you can give it. The text-books you provide for your pupils' use will doubtless subserve a very useful purpose, but do assume the captaincy of your own pedagogical quarter-deck.

Remember that the books in the following list are to be *read through*, not for the sake of the scientific facts they contain but in order that you may learn how the authors *teach*. Some of them are quite out of date as regards development of subject-matter, but for our present purpose that is of no consequence.

1. Mr. Holmyard's *Inorganic Chemistry.*
2. Mr. S. E. Brown's *Experimental Science.*
3. Sir Richard Gregory's text-books (there is usually a collaborator).
4. Professor Alexander Smith's *Introduction to Inorganic Chemistry.*
5. Mr. J. B. Russell's *Notes on the Teaching of Elementary Chemistry.*
6. Shenstone's *Inorganic Chemistry.*
7. Ramsay's *Experimental Proofs of Chemical Theory.*
8. Mr. E. A. Gardiner's *First Year Course in General Science.*
9. Mr. Willings' *General Elementary Science.*
10. Mr. Ivor Hart's *Introduction to Physical Science.*
11. Mr. Calvert's *Heat.*
12. Mr. Hadley's *Electricity and Magnetism.*
13. Professor Ganong's *Teaching Botanist.*
14. Smith and Hall's *Teaching of Chemistry and Physics.*

All these will repay careful reading, no matter what subject of science you have to teach. You will probably learn more about methods of science teaching from books on chemistry than from books on other subjects. Ramsay's book is open to serious criticism. Can you see why? Remember that Ramsay was a front-rank chemist.

The following books are more general, but from the point of view of method they are equally valuable.

15. Huxley's *Physiography.*
16. Huxley's *Discourse on a Piece of Chalk.*
17. Faraday's *Chemical History of a Candle.*
18. Any half-dozen of the Royal Institution series of Christmas lectures to young people. (Those of the last fifteen or twenty years are extraordinarily good from the teacher's point of view. They are full of useful teaching tips, but it must be remembered that they are *lectures*; for teaching purposes they would have to be largely remodelled.)

Now we come to original records of the research of great men of science, records which tell you exactly how great discoverers set to work. Teachers who have read these records readily admit their great indebtedness to them, especially from the point of view of a clear understanding of scientific method.

1. Newton's *Opticks.*
2. Faraday's *Researches.*
3. Cavendish's *Researches.*
4. The Alembic Club *Reprints* (especially Black's experiments on magnesia alba, &c.).
5. Gilbert White's *Natural History of Selborne.*
6. Darwin's *Vegetable Mould and Earthworms.*
7. Priestley's *Different Kinds of Air.*
8. Davy's *The Safety Lamp.*

Lastly we may consider books for particular subjects. Suppose chemistry is the special subject you have to teach. Select a number of elementary books in the subject, written by well-known teachers; note how each writer works out a chemistry course, then compare the different schemes, topic by topic. For instance; what part do lecture demonstrations play in the teaching? what part laboratory work? how are these two things associated? how are theoretical principles established, inductively or deductively? and so on. The following books, amongst others, are well worth comparing: Mr. Holmyard's, Professor Alexander Smith's, Mr. Hooton's, Messrs. Dootson and Berry's, Mr. Miller's. The respective methods differ radically. Compare them and master them, and then you ought to be able to work out a satisfactory method of your own.

Suppose electricity and magnetism is the special subject you have to teach. Amongst other books, read the following: Dr. Jude's, Mr. Kempson's, Mr. Ashford's, Mr. Carl Hansel's, Professor Sylvanus Thompson's (still suggestive in some ways), Mr. Hadley's, and some such book as Mr. Hutchinson's *Technical Electricity.* As before, master the principles of each writer's methods, then work out a method of your own. Disregard the fact that a writer may, from the point of view of technical knowledge, be hopelessly out of date. We are here concerned with *method.* (Never mind *advanced* text-books: advanced science is easy enough to teach. The real trouble is to devise satisfactory methods for boys of 13 to 16, whatever the science subject may be.)

Suppose heat, light, and sound is the branch of physics

to be taught. Tyndall's books, though nowadays obtainable only second hand, should be the first to be mastered; the suggestions as to treatment are delightfully fresh still. And do not begin to teach light without first reading Mr. W. E. Cross's *Elementary Physical Optics* and noting how easy it is to develop the whole subject from the point of view of the wave theory. Wave motion is not an easy subject to teach, but Fleming's *Waves and Ripples* is full of useful teaching suggestions. Read also Professor Poynting's, Professor Watson's, Sir Richard Gregory's, Mr. Brown's, Mr. Willings', Mr. Calvert's, and Mr. Lewis Wright's books, amongst others; compare the different methods, but do not copy them.

Suppose mechanics is the subject. Mr. Ivor Hart's *Introduction to Physical Science* and Mr. C. E. Guillaume's *Mechanics* will give the teacher many useful hints for beginning the subject. So will Todhunter's almost forgotten books, *Mechanics* and *Natural Philosophy*. Then the methods of Sir Richard Gregory and Mr. Hadley, Mr. Eggar, and Mr. Ashford may be compared; and Maxwell's little book *Matter and Motion* is still refreshingly suggestive. Lastly, Mr. Fletcher's article in the 1904 volume of the *School World* should be read through; it is probably the best teaching text-book, if text-book we may call it, that has been written on the subject. Avoid text-books on mechanics that do not develop the subject on an experimental basis. Mach's *Mechanics* is the best book for the history and philosophy of the subject; it is also the best book for making a teacher aware of many possible pitfalls in the handling of many of its principles.

Suppose you are going to give a particular lesson, say in chemistry, the subject chosen being the quantitative analysis of a bronze coin. Consult two or three authoritative standard works, say Professor Hartley's, Professor Thorpe's, and Mr. Newth's. The methods may be broadly the same, but it is almost always possible to fasten on differences of detail that may be of the greatest possible use from the purely teaching point of view. Suppose it is a question of, say, the composition of ammonia. Would you adopt Mr. Holmyard's or Mr. Hooton's

or Mr. Newth's or some other writer's method? You should not adopt any one of them, not because they are not good, but because they are not *yours*. Get what teaching help you can from them all, but let the method you use be the method you have worked out for yourself.

Some writers describe methods which, for teaching purposes, are very much better than others, even though the latter may on the technical side make a stronger appeal to a man with an expert knowledge of his subject. In teaching it is a safe plan always to make some sacrifice of refinement of technique in order to ensure simplicity. An expert chemist or physicist may sometimes be tempted to adopt a method because of its technical "neatness", but if this is more difficult of apprehension to the pupil than some simpler method that may be less attractive to the expert, the latter method should be chosen for teaching purposes. In short, in making a choice of method, always adopt that method which the pupil can follow out and understand clearly. In any demonstration, a single point left vague may be fatal.

Occasionally you may find in a text-book a topic so admirably worked out that you are inclined to "lift" it. As the writer presumably intended it for all the world to use, your sin will be a very venial one! Here are a few of such worked-out topics, chosen quite at random. Try to improve on them—if you can.

1. Professor Alexander Smith: first notions of the qualitative and quantitative properties of gases.

2. Mr. Holmyard: chemical equilibrium.

3. Mr. Willings: introduction to the reciprocating steam-engine and the internal-combustion engine.

4. Shenstone: composition of water.

5. Stewart and Gee: the measurement of time.

6. Mr. S. E. Brown: pressure measurements; experiments with Mr. Fletcher's trolley; laboratory experiments in heat, generally.

7. Sir Richard Glazebrook: first experiments in spectrum analysis.

8. Poynting and Thomson: experiments for illustrating capillarity and surface tension (ignore the mathematics, for present purposes).

9. Professor Ganong: irritable response of plants.
10. Sir Frederick Keeble: osmosis and osmotic pressure.

But never adopt another teacher's method if you can possibly improve upon that method.

CHAPTER V

Laboratory Directions, Bad and Good

Directions Open to Criticism

No part of a science teacher's work is more difficult than the preparation of suitable " directions " or " instructions " for pupils' practical work in the laboratory. Even for his own work at the demonstration table, a previously worked out course of procedure will be necessary, and this will be so far like the detailed laboratory directions provided for the pupil that it will show clearly the succession of steps to be taken for the purpose of building up a logically developed scheme.

We will first give a few examples of laboratory directions open to criticism.

1. Here are successive experiments, taken from an early chapter in a book of *Experimental Chemistry for Junior Students*, written by a well-known professor of chemistry. The subject of the chapter is AMMONIA.

" *Experiment.*—Introduce about one c. c. of Hg into a wide test-tube; gently warm the metal over a flame, and, directing the mouth of the tube away from the person, drop in a fragment of clean metallic *sodium* about half the size of a pea. If the Hg be warm enough, the sodium will at once dissolve in it with a little explosion—if not, heat gently. Then introduce another piece of sodium of the same size, and after its solution a third. A silvery white *amalgam* of sodium is thus prepared which retains the metallic lustre. Now pour out the warm and still liquid amalgam into about 250 c. c. of a cold saturated solution of sal-ammoniac. The amalgam quickly increases to at least

fifteen times its original bulk, and ultimately becomes a large pasty mass, light enough to *float* on the surface of the liquid. This mass can be removed and washed with water; it presents a brilliant and metallic appearance, but it is very unstable and soon decomposes, evolving ammonia and hydrogen gases, and after some time nothing remains but the original mercury."

"There is therefore some experimental evidence as to the existence of a compound radical ammonium, and the close analogies traceable between its saline and other compounds and those of potassium and sodium confirm this view.

"*Experiment.*—Powder half a gram or so of iodine, and add it with frequent stirring to 20 c. c. of AmHO solution; allow it to stand for half an hour until a black powder has completely subsided, then pour away the clear liquid and distribute the black residue on pieces of bibulous paper. Put these in some safe airy place to dry. When the black substance is dry, a touch suffices to make it *explode*, when violet vapours of iodine are evolved. If small quantities are operated upon and reasonable care exercised, the experiment is not attended with danger.

"The black substance is called *iodide of nitrogen*, and is really a mixture of ammonia derivatives. The formula for the chief substance is NHI_2. Analogous bodies are produced by the action of chlorine (chloride of nitrogen) and of bromine (bromide of nitrogen); but these are amongst the most dangerous explosives known.

"Many other derivatives of ammonia are known in which various groups of elements replace one or more atoms of hydrogen in NH_3; we may here give the formulæ of three of these important bodies: $NH_2(C_2H_5)'$ (ethylamine); $NH(C_2H_5)'_2$ (diethylamine); $N(C_2H_5)'_3$ (triethylamine)."

Such experiments are unsuitable for inclusion in the study of ammonia in a beginner's course; they are of no use in developing the first principles of the subject; and they are too difficult at such an early stage. The directions are not detailed enough for beginners, even though they tend to give the case away and make the work mere verification.

2. Next, we take a portion of a chapter on BROMINE, from a school chemistry course written by a former well-known science master at one of the leading public schools.

"SOME PROPERTIES OF FREE BROMINE

"1. Notice the offensive odour of bromine, taking care not to expose the eyes to the vapour, and only to smell it when freely diluted with air.

"2. Place a cork in a bottle containing bromine, and observe that the cork is rapidly destroyed.

"3. Put a drop of bromine in some water. Notice that it sinks (D = 3·19), partly dissolving and giving a yellow solution.

"4. Cool some bromine water to 4°. Crystals having the composition $Br_2 10H_2O$?, form.

"5. Add a drop of bromine water to solution of iodide of potassium containing starch. Iodine will be liberated and form blue iodide of starch.

$$\text{“} 2KI + Br_2 = 2KBr + I_2.$$

"6. Pass hydrogen through a U-tube containing fragments of pumice stone soaked with bromine, and provided with a jet; ignite the mixture which escapes. Clouds of dense colourless acid fumes, resembling those of damp HCl, will testify to the formation of an acid fuming gas. This is hydrogen bromide (HBr).

"7. Place some Dutch gold in bromine. The metal will combine with the bromine, but much less readily than with chlorine.

"8. Place a strip of Turkey red twill in some bromine water. It will be bleached much less rapidly than when chlorine is employed."

With such instructions as these, the pupils would engage in mere mechanical routine. They would know exactly what is going to happen, or at any rate what is supposed to happen, before they performed an experiment. In such circumstances, is the average boy likely to engage in active observation?

3. The following is taken from an early page in an American professor's book written specially for those who are beginning organic chemistry. The pupils have, presumably, done a certain amount of inorganic work previously, though nothing is said about this.

"Chloroform, $CHCl_3$, and Iodoform, CHI_3

"Chloroform or tri-chlor-methane is made by treating ordinary alcohol with bleaching powder. The action is deep-seated, involving at least three different stages. Chloroform is a heavy liquid, of specific gravity 1·526. It has an ethereal odour, and a somewhat sweet taste. It is scarcely soluble in water. It boils at 62°. It is one of the most valuable anæsthetics.

"*Experiment.*—Mix 550 g. bleaching powder and $1\frac{1}{4}$ litres water in a 3-litre flask. Add 33 g. alcohol of sp. gr. 0·834. Heat gently on a water-bath until action begins. A mixture of alcohol, water, and chloroform distils over. Add water and remove the chloroform by means of a pipette. Add calcium chloride to the chloroform, and, after standing, distil on a water-bath.

"*Iodoform*, which is extensively used in surgery, is made by bringing together alcohol, an alkali, and iodine. It is a solid substance, soluble in alcohol and ether, but insoluble in water. It crystallizes in delicate, six-sided, yellow plates. Melting-point, 119°.

"*Experiment.*—Dissolve 20 g. crystallized sodium carbonate in 100 g. water. Pour 10 g. alcohol into the solution, and after heating to 80°, gradually add 10 g. iodine. The iodoform separates from the solution."

The directions for these experiments are inadequate. They require redrafting and supplementing. To give a mere list of properties, without suggesting some experimental method of at least verification, is unsatisfactory.

4. Here is an example from a school text-book of physics. Apparently the author is a specialist teacher of the subject.

"Measurement of the Heat of Fusion

"Let it be required to find approximately the quantity of heat that disappears during the melting of one kilogram of ice. This quantity is most readily determined by the *method of mixtures*.

"*Experiment.*—Weigh out 200 gm. of dry ice chips (dry them with a towel), whose temperature in a room of ordinary temperature may be safely assumed to be 0° C. Weigh out 200 gm. of boiling water, whose temperature we assume to be 100° C. Pour the hot water upon the ice, and stir it until the ice is all melted. Test the temperature of the resulting liquid.

"Suppose its temperature is found to be 10° C. It is evident that the temperature of the hot water in falling from 100° to 90° would yield sufficient heat to raise an equal mass of water from 0° to 10° C. Hence it is clear that the heat which the water at 90° yields in falling from 90° to 10°—a fall of 80°—in some manner disappears. At this rate, had you used 1 K. of ice and 1 K. of hot water, the amount of heat would be 80 calories. Careful experiments in which suitable allowances are made for loss or gain of heat by radiation, conduction, absorption by the calorimeter, &c., have determined that *80 calories of heat are consumed in melting 1 kilogram of ice.*"

Give the instructions to a class of beginners, watch the work in progress, then examine the class to find out what they have learnt.—The instructions are neither adequate nor lucid, and the reasoning in the second paragraph is unsatisfactory. The words "suppose" and "had you used" are out of place in reasoning from experimental data.

5. Another example from physics, from an American book by an American professor and a collaborator.

"MUSICAL SOUNDS

"All musical instruments are capable of giving out sound-waves of regular intervals. The vibrating spring in the following experiment illustrates the action of a tuning fork.

"*Experiment.*—Take a long straight piece of clock-spring and fasten it in a vice or clamp, leaving about 40 or 50 cm. projecting horizontally. Set this part vibrating and note the regularity of its swings, observing that, like the beats of a pendulum, they take about the same length of time, whatever the length, or width, of the swing.

"Shorten the vibrating part, and observe the effect upon the quickness of the swing. Shorten it to 2 or 3 cm., and observe that now it gives out a good musical note.

"A long piece of rubber tubing, fastened at the ends and stretched, illustrating the action of the strings in a piano or violin, would be found to vibrate regularly with a quickness depending on the degree of tension."

Observe "that they take about the same length of time"! Ask a class to work the experiment, and then to write down

how they were able to tell that the swings took about "the same length of time". Contrast the lucid instructions given by Stewart and Gee (pp. 186–91 of their book) on the isochronism of torsional vibrations. The experiment, as above described, would certainly not lead to the observation called for.

Directions which may be regarded as Models

We now give examples of directions which have been well thought out, and are exactly what the pupils need in order that they may set to work in a really intelligent way.

1. The first is taken from Mr. Holmyard's *Practical Chemistry*, pp. 101–2.

"PREPARATION OF NORMAL SALTS

"Normal salts may be prepared in several ways, the choice of a method of preparing a given salt being governed by consideration of convenience.

"*Method 1. By Neutralization.*—If the acid and base are both soluble, the salt may be obtained by neutralization. Prepare sodium chloride in this way:

"Dissolve about 5 gm. of caustic soda (NaOH) in about 30 c. c. of distilled water in a beaker. Pour *most* of this solution into a clean evaporating dish, but reserve a few c. c. in the beaker. Mix some of the laboratory 'concentrated hydrochloric acid' with its own volume of water, and gradually add the diluted acid to the caustic soda solution in the basin. After the addition of every few drops of acid, stir the liquid well, and take out a drop of it on the end of a glass rod. Test this drop with both blue and red litmus paper. The solution will at first be alkaline, i.e. it will turn the red litmus blue. Neutrality is reached when the solution has no decided effect on the litmus of either colour. Continue the addition of acid until this stage is reached. If you accidentally add too much acid, bring the solution back to the neutral point by careful addition of some of the caustic soda solution which you have reserved in the beaker. Take care to get the solution in the basin *exactly* neutral; the experiment as a whole is so simple that if you fail in this point you must be considered to have failed in the experiment altogether.

"When the solution is neutral, carefully evaporate it over iron

gauze. Salt is not much more soluble in hot water than it is in cold, so that you must evaporate the solution practically to dryness. Allow the basin to cool, scrape out all the crystals on to a pad of filter paper and allow them to dry.

"Taste the crystals; you will find, if you have been careful in neutralization, that they have the flavour of table salt.

"The equation for the reaction is:

$$\text{“ } NaOH + HCl = NaCl + H_2O. \text{”}$$

Then follow other methods of preparation, all given with the same happy lucidity. The whole book is worth reading through for the sake of its lucidity alone. Many of the experiments are worth marking down for their own sake. See, for instance, Experiment 34 (p. 44) on catalysts.

2. The second is taken from Smith and Hale's *Laboratory Outline*, p. 65. The letter "R" signifies that the pupil is to "refer" to Alexander Smith's *Introduction to General Inorganic Chemistry.* The notes of interrogation signify that definite questions have to be answered.

"SULPHUR

"(1). In a very dry test-tube, place a very small piece of roll sulphur with 2 to 3 c. c. of carbon disulphide and shake. Allow the clear solution to evaporate spontaneously (i.e. without the aid of heat) in a watch-glass [Hood], and describe the crystals [R 138] (?).

"(2). In a dry test-tube place about 5 gm. of roll sulphur, melt the substance with the least possible application of heat (the material must remain pale yellow), and pour into a beaker of cold water. Dry some of the product with filter paper, and test its solubility in carbon disulphide as in (1).

"(3). Melt about 10 gm. of sulphur in the same test-tube, and heat until it boils (?). Note the changes in colour and fluidity that occur. To learn the nature of the substance formed by heating, chill the sulphur while it is boiling vigorously, by pouring it suddenly into cold water (?). Note the physical state of the product, dry a part with filter paper, and examine its solubility in carbon disulphide (?). Set the remainder aside for a few days, and then study its appearance and solubility again. Keep also the test-tube from which it was poured, and examine, at the same time, in both these respects, the sulphur

which remained adhering to its walls, and was not cooled so suddenly (?). Account for the change when sulphur is heated, and the differing results of rapid and slow cooling [R 369].

"Why are we convinced that none of the changes was due to interaction with the water?

"(4). Mix in a mortar 2 gm. of iron filings and 1 gm. of powdered sulphur. Transfer to a dry test-tube and heat gently (?). When cool, break the test-tube in a mortar and test the black product (?) for solubility in carbon disulphide."

3. The following is taken from the List of Exercises in Physics, by Professor Hall, required of candidates for admission to Harvard.

"FRICTION BETWEEN SOLID BODIES

"*Apparatus.*—A spring balance of about 250 gm. capacity; a rectangular wood-block about 8 cm. × 8 cm. × 4 cm.; a smooth sheet of paper about 18″ × 12″.

"(1) *First consider the velocity of the motion; that is, ask whether the force required to keep up a slow steady motion is greater or less than that required to keep up a more rapid steady motion.*

"Lay the block upon one of its broad sides, and attach it to the spring balance by a thread passing around but not under the block. Load the block with weights until the force required to maintain a slow steady motion is about 3 oz. Draw the block parallel to its *grain* along the sheet of paper several times with a very slow steady motion, and then several times with an equally steady motion two or three times as fast. (As the paper is likely to grow somewhat smoother under the repeated rubbing, do not make all the slow trials first, but change from slow to fast, and fast to slow a number of times.)

"Record your conclusion as to whether the slow or more rapid motion requires the greater force.

"(2) *Next try to find out whether, the total weight being the same as before, it is easier or harder to draw the block on a narrower side than on a broad side.*

"Use the same block and the same load of weights, pulling it now, as before, parallel to its grain. (The sides of the block must always be clean, and the broad and narrow sides as equally smooth as possible.)

"Record your conclusion as to whether the broad side or the narrow side offers the greater resistance to the motion.

"(3) *Finally, ask what connexion there is between the total mass drawn and the force required to draw it.*

"For this purpose, vary the weights placed upon the block, using not less than 6 oz. for the least, and as much as 16 oz. for the greatest load.

"Add to the load in each case the weight of the block itself, and make the record in the following form, W being the load, and *b* the weight of the block:

W + *b*	F (Force required)
....	....
....	....
....	....
....	....

Look for any simple relation between (W + *b*) and F.

"(In the next part of the investigation, the block was made to slide down a sloping board covered with a sheet of paper, arrangements being made for varying the steepness of the board.)"

4. The next example is from Mr. J. B. Russell's *Notes on the Teaching of Elementary Chemistry*, intended for young beginners.

"SOME EFFECTS OF HEAT ON SUBSTANCES

"Heat, one at a time, each of the substances named in the list as directed, and try to see all that happens.

Mercury.	Soda.	Lead Nitrate.
Nitre.	Borax.	Sal-ammoniac.
Iodine.	Red Lead.	Blue Vitriol.

"(1) Describe the substance in such a way that a person after reading your description might readily pick out the right substance from among the others.

"(2) Place on a strip of paper, bent in the form of a shoot, about sufficient of the substance to cover a shilling, and introduce it into a clean dry test-tube without soiling the sides.

"(3) Heat the tube at first gently and then more strongly. Watch *all* that happens. Allow to cool and examine the residue.

"(4) Immediately after each experiment write down an account of all that you have observed, and in addition answer the following questions:

"(i) Does the substance left in the tube appear to you to be the same as, or different from, the original substance?

"(ii) Does any substance appear to leave the tube?—if so, describe it.

"(iii) From which of these substances are *two*, or more, distinct substances obtainable?"

5. Here is an example from Professor Ganong's *Teaching Botanist*. The author claims to present to his class every new topic in the form of " a problem so arranged as to be solved through proper inductive processes by the pupils' own efforts ".

" THE ANATOMY OF THE SEED

" I. (*a*) Study the outside of the dry Lima Beans; compare several specimens and observe what features are common to all and what are individual; minutely observe:

(1) What is the typical shape?
(2) What is the colour?
(3) What markings have they?

" Answer, as far as possible, by drawings made twice the natural size; add notes to describe features which drawing cannot express.

" (*b*) Remove the coatings from soaked seeds.

" (1) What effect has the soaking had upon the markings, size, and shape?
" (2) How many coats are there?
" (3) Do the external markings bear any relation to the structures inside?
" (4) What shapes have the structures inside, and how are they connected with one another?

" Answer, as before, by drawings and notes.

" II. Study fully in the same way the Horse Bean.

" III. Describe the *resemblances* and the *differences* of the Lima and the Horse Beans."

6. In contrast with the last, we give an example from another botany text-book: what *is* the contrast?

"ENDOSPERMIC SEEDS

"*The Date.*—Examine a date seed (i.e. the '*stone*'). Notice the deep groove along one side. Scrape the surface on the other side, to see the small embryo embedded in the stone (endosperm). Cut the stone across at this point; then dip the stone in dilute sulphuric acid and apply iodine (test for cellulose). Plant some date-stones in damp sawdust or soil, set in a warm place (a heated greenhouse if possible), and sketch stages in their germination. Open the stone in some of the seedlings, and then notice the softening of the stone and the extent to which the cotyledon has grown inside it. Notice in sections of the stone that the cell-walls become thinner, and that starch appears in the young root and shoot, in darkness as well as in light. The digestion (conversion into sugar) of the reserve food (cellulose) is due to the secretion of a ferment (cytase) by the cotyledon."

The suggestions for the systematic examination of the seed are excellent, but there is hardly anything left for the pupil to discover for himself. He has to "notice" things that he is told may be seen. Suppose that he wrote in his note-book: "I cut sections of the stone and noticed that the cell-walls had become thinner and that starch appeared in the young root and shoot." How could the teacher tell whether the boy had actually done the work and had not spent the half-hour in idleness? Why should a boy trouble to *notice* a thing, when it means trouble that it is entirely unnecessary to take?—These instructions just fall short of being a model of what instructions should be. For the purely private worker, they are excellent.

A few other good examples may be appended:

7. Glazebrook and Shaw's *Practical Physics*, pp. 152–5: to determine the value of *g* by observations with the pendulum.

8. Stewart and Gee's *Practical Physics*, pp. 24–6: to obtain and fix magnetic curves.

9. Professor Armstrong's *Teaching of Scientific Method*, p. 230: the comparative study of silver and lead (for fairly advanced pupils).

10. Mr. T. G. Bedford's *Practical Physics*, for present-day methods as practised in the Cavendish Laboratory. Half a

dozen of these experiments would give advanced boys a good idea of reasonably refined methods of measurements; say, linear expansion experiments, determination of the mechanical equivalent of heat, determination of the magnifying power of the microscope, resonators, the relative capacities of condensers, and the study of the motion of a pendulum.

Here are a few examples of exceptionally well-written and lucid records of observations: Lubbock's *Ants, Bees, and Wasps*, pp. 176–81; Sir R. Lankester's *Science and Education*, pp. 128–9 (for Tyndall's explanation of the optics of a wet towel), and pp. 164–5 (for the process of repair in a severed Achilles tendon); the examples given in *The Writing of Clear English*, pp. 123–70. For a well-written-up account of a topic treated historically, see Mr. G. H. Wyatt's story of the *Barometer*, with references to Galileo, Torricelli, and Pascal, in the *School World*, for May, 1914.

CHAPTER VI

A Common Cause of Failure

First Illustrative Example: Boyle's Law

A common cause of failure, especially at the demonstration table, is due to one or both of two things: (1) the main purpose of the investigation has not been made clear to the pupils; (2) the pupils are unprepared by previous training for the new lesson in hand.

We may illustrate the point, first, by reference to the usual "verification" of Boyle's law. Obviously the pupil must already be familiar with (*a*) the nature of a ratio, and (*b*) fluid pressure.

It is not unusual to find the experimental results from a Boyle's law apparatus tabulated under p, v, and pv, for the

teacher to point out that pv is constant, and that *therefore* the pressure is proportional to the volume, and to leave it at that, although the pupils may never in their lives have had a lesson on ratio and proportion. Boyle's law is too difficult a subject for a first lesson in proportion. The *notion* of a ratio and of proportion must already be clearly apprehended, or the lesson on Boyle's law is bound to be ineffective.

One or two simple cases of inverse ratio might suffice by way of introduction. For instance:

1 man can build a wall in 64 days.
∴ 4 men can build a wall in 16 days.
∴ 16 men can build a wall in 4 days.
∴ 64 men can build a wall in 1 day.

Such a simple illustration is useful, despite its inherent absurdity in practical life. The boy sees that the products of the numbers of men and days are constant; that a ratio composed of any pair of selected terms from the first column is equal to the inverted ratio of the corresponding pair of terms in the second column. Now graph the result and make boys familiar with the general *form* of the rectangular hyperbola (the name is of no consequence). Of course all this is unnecessary if in algebra the boys have already reached the stage of graphing $y = \frac{1}{x}$. But it is fatal to approach Boyle's law until the boys have a clear, if elementary, notion of inverse proportion.

In the next place, the problem involves the comparison of balancing columns of fluids—a liquid against a gas. It is an *application* of the principles of fluid pressure, and these principles must therefore have been studied already and clearly understood. Boyle's law itself, as a new thing, is quite enough for boys to have to understand in one lesson. The previous lessons on fluid pressure would probably include:

1. The ordinary U-tube: the common level of the surfaces of the water columns in the two arms.
2. Ditto, the U-tube having arms of different bores.

3. Ditto, Pascal's vases: the *heights* of the columns are the same, whatever the volumes.
4. Water balancing mercury in a U-tube; how the densities may be compared by measuring the vertical heights above the " surface of separation ". Dwell on the fact that the mercury in the bend, below this particular surface level, would remain in equilibrium if the liquid columns above were removed, and that therefore these two columns must balance each other.
5. The inverted U-tube (Hare's apparatus). Show *why* the columns balance: the full atmospheric pressure is the same on the liquid surfaces in the two beakers, and the reduced atmospheric pressure is the same on the surfaces of the two liquid columns. Vary the the form of the apparatus by using tubes of different bores, irregular tubes, and tubes out of the vertical. The result is always the same if vertical heights are measured: this measurement in terms of vertical heights is the important point. (It is unnecessary to develop Pascal's principle mathematically at this stage.)
6. The mercury barometer: again merely an affair of balancing columns—a column of mercury balancing a column of air—measured vertically from the *same surface level*.

By this time the pupils ought to be prepared to understand the usual procedure of a Boyle's law investigation.

But how to begin?

Perhaps in this way.—I take an ordinary gas jar with a well-fitting piston. I push down the piston and so press the contained air into a smaller volume. The farther I push down, the harder the work becomes. Is there any relation between the amount of pressure I exert and the volume of the air under the piston? How can we investigate this? Suppose I push down the piston until I have halved the original volume of air and then measure the pressure I am exerting; then press

down again, until I have halved the remainder, and again measure the pressure; and so on. Would this tell me what I want to know? Yes. But how am I to measure the pressure? —that is the question. Here is the plan that Boyle devised.

And so on.

The boy now knows *exactly what the investigation is to be about*. And he is already familiar with the elementary principles of fluid pressure and with the principle of inverse ratio. There is thus just *one new thing* for him to learn, viz. how to use his knowledge of fluid pressure to find the relation between p and v. When he has found this relation, he will recognize it as an old friend, viz. the relation of inverse ratio.

The fragment of the rectangular hyperbola sometimes graphed from the values experimentally obtained is seldom recognizable for what it is, and is of no value *if* deductions are to be drawn from it.

That Boyle's law is only an approximation would be mentioned to a Fifth Form and would be explained in a Sixth, but would not be mentioned to a Fourth.

Second Illustrative Example: The Law of Charles

We may select for discussion the procedure laid down by Professor William Ramsay in his little book *Experimental Proofs of Chemical Theory for Beginners*.* It begins:

"*Expansion of Gases by Heat.—Law: all perfect gases, when heated, expand* $\frac{1}{273}$ *of their volume, measured at* $0°$ *C., for each rise of* $1°$ *C.* (Law of Charles). Required to prove this law approximately for air, between the temperature of the room and the boiling-point of water."

Then follows a description of the apparatus used (the usual 300 c. c. round-bottomed flask heated in a pot of boiling water), and details of the experiment. These details are as exact,

* This curiously misnamed book should be in the possession of every science teacher. The experiments for verifying laws are particularly well chosen. But of course we cannot "prove" theory. We may perform an experiment to verify a law, or to confirm the possibility of the truth of some hypothesis. But if we could "prove" theory to be "true", the theory would become identical with objective reality, and cease to be "theory" entirely.

definite, and practical as might be expected from so eminent a chemist. Nothing at all is said, however, by way of explanation, and even the meaning of x has to be inferred by the pupils. Finally, this scheme is given:

Calculation of results.

Capacity of flask	a
Water which has entered on cooling	b
Volume of air at lower temperature	$a - b$
Temperature of cold water	t
Temperature of boiling water	$100°$
Increase of volume measured at 0° per degree ..	$\frac{1}{x}$

The relation to be found is as follows:

$$\frac{\text{Volume of cold air}}{\text{Volume of hot air}} = \frac{1 + \frac{1}{x}t}{1 + \frac{1}{x}100}.$$

Multiplying the last two terms by x,

$$\frac{a - b}{a} = \frac{x + t}{x + 100},$$

$$\therefore x = \frac{(100 - t)a - 100b}{b}.$$

A somewhat similar scheme is given by the writers of many other text-books.—In order to see if the scheme is workable, I have given it to classes of intelligent boys on many occasions, but never have I obtained intelligible results. Fairly accurate results, from the point of view of mere measurement, may be obtained, of course; but a comprehension of the purpose and of the procedure, no.

The first thing to do is to make the pupil understand clearly the purpose of the experiment. We may argue in this way:—

The purpose of the experiment is to find out *the increase in volume of a cubic centimetre of air, when it is heated from 0° C. to 1° C.*

We cannot in practice work with a single c. c. of air (about a third of a thimbleful), and we cannot in practice heat the gas just from 0° to 1°. But we can work with a larger quantity of air, and heat it through a greater range of temperature. Will this do? Can we obtain from such a result the result we are seeking? Let us try.

Suppose I take a flask which will hold, say, 546 c. c. of air at 0° C., heat it up to 80°, and then find that the volume of air is 706 c. c.

Evidently I used 546 times as much air as I really wanted, so I must divide the increase by 546; and I heated it 80 times as high as was really necessary, so I must also divide the increase by 80.

The increase in volume was 706 c. c. – 546 c. c., viz. 160 c. c.

Hence I may say:

Since 546 c. c. at 0° has increased at 80° by 160 c. c.,

$$\therefore 1 \text{ c. c. at } 0^\circ \text{ has increased at } 80^\circ \text{ by } \frac{160 \text{ c. c.}}{546},$$

$$\text{and } 1 \text{ c. c. at } 0^\circ \text{ has increased at } 1^\circ \text{ by } \frac{160 \text{ c. c}}{546 \times 80} \text{ or } \frac{1}{273} \text{ c. c.;}$$

i.e. 1 c. c. of air, in expanding from 0° to 1°, has become $1\frac{1}{273}$ c. c.

We call this increase of $\frac{1}{273}$ the *coefficient of expansion*. (A coefficient is merely a number or the fraction of a number, used to measure some property of a substance. It is always the same for the same substance.)

It is useful to write the result in the form of an algebraical formula:

Let V_0 = volume of the air at 0° C.
Let V_t = volume of the air at t° C. (the temperature to which it is heated).
Let x = the coefficient of expansion.

Then $x = \dfrac{V_t - V_0}{V_0 \times t}$, which is exactly like the arithmetical fraction above.

But how is such an experiment to be worked *in practice?* We ask the boys to make suggestions. They will be puzzled and will fail. They will probably say: "If we heat to 100° a flask full of ice-cold air, the air will expand and some of it will be driven out, but how is it possible to measure this expelled portion?" We answer: "It would be so difficult to do it satisfactorily that we do not attempt it, and we adopt an entirely different plan, a plan that seems to be the reverse of the other. We take a flask with air already heated to 100°, let it cool down to 0°, then measure the contraction."

A general preliminary discussion of the actual experiment to be performed may now take place, the apparatus being on view, and the blackboard being used freely:—

We use a flask, corked, with a short glass tube through the cork, and a short piece of india-rubber tubing slipped over the glass tube. A clip serves to close the tubing.

We obtain the volume of the flask by filling it with water and measuring this water in a measuring jar. We will suppose it to be 300 c. c. The flask is now emptied and dried.

We now plunge the flask, full of air, into boiling water, so that it is completely covered, except the india-rubber tubing. The air expands, and some of it escapes. Keep the flask in the water for some minutes so that the contained air is heated to 100° C. Close the clip, and lift the flask out. Now invert the flask and immerse it in a vessel of cold water plentifully supplied with pieces of ice, and let the contained hot air cool to 0°. Open the clip under water; some of the water rushes in, the air having contracted. Pour this water out of the flask and measure it in a measuring jar. Suppose it to be 80 c. c. *Then we know that the volume of the ice-cold air was (300 — 80) c. c., i.e. 220 c. c.*

We may now argue that a volume of 220 c. c. of air at 0° C. would expand to 300 c. c. if heated to 100° C., and we can therefore find the coefficient as we did in the imaginary case we began with.—It seems rather a backward plan of setting to work—to talk about measuring expansion, when we really

measured contraction; but if you think about it you will agree that our reversal of the process is quite legitimate, and gets us over a practical difficulty.

A preliminary discussion of this kind will make the boy familiar with the broad principle to be investigated, and with the unusual form of practical procedure in the experiment. He need not be worried with such small points as pressure-differences at this stage; they can be taken up when the main principle has been mastered.

It is always preferable, at first, to work with the two temperatures 0° and 100°. To work at "the temperature of the laboratory" for the lower temperature merely serves to confuse the main issue and to increase the boy's difficulty of always working from first principles. Never use a formula in such cases as these if it can possibly be avoided. The main thing is to get the *physical notion* clearly grasped. It is always undesirable to let a boy think that when he is working out algebra he is doing real physics.

The alternative plan of using a horizontal narrow glass tube with a mercury index, and with a thermometer attached, the whole enclosed in a steam-heating glass jacket, is not to be recommended. The boy has then to measure lengths only, and the all-important idea of volume is apt to be lost sight of.

Said a boy on being asked a question at the end of a particular lesson on this subject: "I am awfully sorry, sir, but although I was easily able to follow Mr. X in everything he said, I do not understand at all what he meant to teach us."—Always make quite sure that the boys really do understand the nature of the problem they or you are investigating.

CHAPTER VII

The Content of the Normal Science Course

The Course up to School Certificate Stage

The School Certificate examination forms a definite dividing line between the four or five years' general science course, extending from about the age of $11\frac{1}{2}$ or 12 to that of $16\frac{1}{2}$ or 17, and the more exacting specialized course which usually extends over the next two years in preparation for the Higher Certificate or for entrance to the universities. The former course applies to all pupils, and for some it will be the only course. It is therefore desirable that it should be, as far as possible, comprehensive and complete in itself. It should not consist merely of a preliminary training in preparation for advanced work; it should be sufficient to enable a boy to obtain some insight into science as a whole, however limited that insight may have to be. A treatment on broad lines is thus essential. There is no time for the inclusion of much purely technical knowledge, and great discrimination is necessary in deciding what to include in and what to exclude from this preliminary course up to $16\frac{1}{2}$ or 17.

That physics and chemistry will always be the main subjects is inevitable. They form the foundations of all other branches of science. But this does not mean that biology should be excluded, as is often the case. Biology is an essential subject of any school science course.

The best work before 12 or 13 is not easy to decide upon, for boys and girls are not then old enough to face the difficulties of a formal training in physics and chemistry. Nature study in some form is often begun at the age of 7 or 8, and in its broader aspects it may be profitably continued until after 12. It was the fashion for many years to include " physical measure-

ments " in the preliminary science course, but the subject is the concern of the mathematical staff. Time cannot be spared for it in the science course. There is a great deal of preliminary work that may be done in the laboratory at this stage—the use of test-tubes and flasks, filtration, decantation, evaporation, distillation, the use of the bunsen, the use of the balance, the heating of common substances and the alteration in their weights, the study of the U-tube, expansion, the simpler properties of air and water, and written descriptions of all the experiments performed. This kind of work has to be done sometime, and it can be done by young children easily and profitably.—We shall return to the subject in the next chapter.

Then come the four (or five) years of systematic work in physics, chemistry, and biology. In some girls' schools, the last two of the four or five years is often devoted mainly to botany. In other schools the only biology possible is squeezed into the summer terms of the two years preceding the School Certificate year, and sometimes biology is omitted altogether.

The old argument that children cannot appreciate experimental investigation, and cannot therefore profitably begin science until about 14½, has rightly been given up. Experience shows that physics and chemistry may be begun, at least in an informal way, at 12½ or 13.

Those schools that include in the five-years' course nothing but elementary mechanics and heat are not treating science seriously; indeed, they are treating it contemptuously. No boy should leave school thinking that science consists of only physics and chemistry, and to turn him out with such a scanty fare as one small portion of physics is to turn him out hungry indeed.

It is a common criticism that even in schools where science receives serious attention, the four- or five-years' course consists of *only* physics and chemistry. Even so, the subject-matter included in the course is often unduly academic, and scarcely touches applications to everyday problems. Principles are often taught with little or no reference to the phenomena of

nature they explain, and the course is planned as if the main object was to lay the foundations for specialized study at a later period. It is a common thing for a boy to be given a good training in laboratory methods, and yet to leave school without knowing either that he has been devoting four or five years to the study of energy under different guises, or that the conservation of energy is a great principle underlying the whole. There is something seriously wrong in a science teacher's outlook when time is spared for lessons on, say, that elegant instrument the quadrant electrometer, and still more time is spared for lessons on the chlorides of sulphur, and yet no time is devoted to the consideration of such things as the thermionic valve or common soap. Phenomena which are matters of everyday experience should never be lost sight of, and the pupils' interest in the world around them should constantly be aroused and sustained.

When the systematic course begins at about 13, let the principal aim be not only to provide an exacting mental discipline and a training in logical method but also to make the pupils acquainted with the principles and foundations of common physical phenomena. In any course, a good deal of quantitative work will naturally be necessary, for measurement is the main avenue to exact thought in physical science; but do not let time be wasted in emulating the exact measurements of the National Physical Laboratory. It is a mistake to spend time in this way. In planning out a physics course, let all branches be fairly represented. The question of syllabuses will be dealt with in a future chapter, but it may be said here that no elementary physics course is satisfactory that does not include considerations of the heating and lighting of the home by gas and electricity; electric traction; telegraphy and telephony including "wireless"; common optical instruments including the spectroscope; stringed musical instruments; engines, machinery, and mechanism. Do not begin drawing up a course by reference to any examination syllabus or to any book. Jot down a list of all natural phenomena, discoveries and inventions, scientific generalizations and theories, that you

feel your pupils ought to know and that you can deal with in the time at your disposal. Then sort these out under different branches of physics (also of chemistry and biology if you are planning a more general course), decide what principles of physics must be established for the proper elucidation of the phenomena, and arrange these principles in logical order according to a possible general development for teaching purposes. *Now* turn to your examination syllabuses (unfortunately, this is necessary), and add to your provisional course any examination topics not yet included. Never begin by giving pride of place to an examination syllabus. Such a syllabus is never drafted for teaching purposes; it is merely a medley of topics on which questions may be asked.

In any elementary course of physics that is to be at all satisfactory, the inclusion of mechanics, heat, light, and current electricity is essential. Static electricity may be sacrificed without much loss; so may, perhaps, the greater part of sound, which, with the exception of the monochord and stringed instruments, may be postponed for treatment in the later Sixth Form course. Wave motion is important enough to be regarded as a subject in itself; it goes to the foundations of every branch of physics. An elementary treatment of waves is possible and is necessary in the Fifth Form; the fuller treatment must be reserved for the Sixth.

In drafting a course of instruction in chemistry, reduce all purely technological considerations to a minimum, consistent with a rational approach to, and development of, the Periodic Law. Bring the subject into contact with daily life, and choose your topics accordingly. Do not forget that the study of equivalents is just a necessary preliminary for establishing the laws of combination, that these laws are merely generalizations of experimental *facts*, and that hypotheses and all points of theory follow and do not precede those laws. Such topics as diffusion, solution, and electrolysis must be included even in an elementary course. Avoid quantitative experiments that take a long time; they may be reserved for the Sixth Form—if they are necessary at all. Manufacturing processes are

always worth touching upon, but never in minute detail. Ignore the old dividing line between inorganic and organic chemistry; there is a good deal in organic chemistry that should be included in any elementary chemistry course. So with chemical processes in the living plant; remember how large a part nitrogen plays here.

The last two years of the four- or five-years' elementary course in chemistry is often open to criticism; the sequence of topics is too much of a medley, and is not threaded on any kind of logical string; the course is dominated by quantitative work, and yet the purpose of this is not realized as being just an essential factor in the rational development of chemical theory; facts and hypotheses are confused; reasoning is faulty. For instance, the pupils often cannot give a rational account of the basic facts that led up to the kinetic hypothesis of gases; or explain how Avogadro's hypothesis provides a rational basis for the law of Gay Lussac. They cannot fit the facts they have learnt into a satisfactory mosaic. As a boy once said to me: "All the facts I have learnt in chemistry seem to be just a mixture, and not a compound."

The theory of chemistry must be built up step by step, from plane to plane, and the learner must be conscious of the building. He must know what facts form the foundations, and how each stage of the building rests on the stage below. In the whole range of science there is no possible scheme of work so logically perfect as the scheme underlying that wonderful edifice, the Periodic Law.

Girls' Schools

Only in recent years has science in girls' schools been given a place of equality with other subjects, and even now the argument is sometimes used that few girls are capable of learning physical science. The consequence is that botany still tends to survive as a principal science subject. Twenty or thirty years ago, the botany taught was very little more than the identification and classification of wild flowers; the

study of function was not seriously undertaken; and as for a preliminary course in physics and chemistry, that was considered to be something alien and wholly unnecessary. Moreover, botany has always been regarded as a soft option for girls who (so runs the argument) cannot do mathematics. " Botany is such a nice easy subject for the slow girls, and, besides, *all* girls ought to be trained to undertake the dainty daily duty of decorating the drawing-room prettily." It is significant that in some schools botany is not even looked upon as a branch of science: " She is not good enough for science, so she takes botany instead."

But botany has now become a very serious subject of study, and, in my opinion, it is much more difficult to teach than either physics or chemistry. The plant is now treated as a living, breathing, feeding, growing thing. The study of function rather than morphology now takes the first place; and since " life " (whatever that may be) tends greatly to obscure the underlying physical and chemical processes, fallacious reasoning is common even among advanced students. As for beginners, they are often hopelessly baffled by the complexities of the problems underlying plant biology. Let it never be said that botany is an easy subject. It requires a thoroughly competent botanist with a large share of teaching skill to deal with the subject properly, and it is exceedingly doubtful if girls get out of it anything like so good a training as boys do from physics and chemistry.

Some university professors urge that even if girls come to them in order to read for botany honours, it does not matter at all if the subject has never been begun at school. What they specially desire is that the girls shall have been well grounded in physics and chemistry.

If botany is the principal subject taught, its selection must be justified: the teaching must provide a rigorous training in the methods of scientific reasoning and investigation.

If the future professional careers of the majority of the abler girls are considered—teachers of science and mathematics, teachers of domestic subjects, doctors, dentists, phar-

macists, factory and sanitary inspectors, welfare workers, and health visitors, engineers (there are already several successful women engineers)—a knowledge of physical science is clearly essential, and thus, whether botany is included in a school course or not, physics and chemistry must always be taught. Or, consider for a moment the future of electricity. In ten or fifteen years' time, even village cottages will have complete electric installations, and a knowledge of the elementary principles of electrical science will be almost as necessary as a knowledge of arithmetic. A school science course which ignores electricity altogether, as science courses in some girls' schools still do, is assuredly open to serious criticism. In short, no adequate excuse can any longer be put forward for the omission of physics from the science course of any girls' school.

It is often urged that hygiene is a suitable subject of science for girls. The point will be dealt with in a future chapter. So will domestic " science ", as it is sometimes called.

There is much to be said for substituting general biology for botany, and including the subject in the Upper and Middle Forms of all schools, boys' as well as girls'. Every boy should know something of the life history of both animals and plants, and something of the physiology of his own body. But whatever may be said about systematic botany, systematic zoology and animal dissection is work more suitable for the Sixth Form than for younger children. And in any case it has to be borne in mind that biology does not lend itself so readily as physics and chemistry to experiments of the kind necessary for a full appreciation of the principles of scientific method.

Sixth Form Science

Boys and girls who have acquitted themselves creditably in the School Certificate examination are ready for a more intensive study within a limited range. In other words, some measure of specialization is now possible. But this specialization should not be narrowed down to a single subject: that

may come at the university. Rather it should connote a small group of allied subjects. For boys, chemistry and physics is a favourite group; for girls, botany and chemistry. Boys almost always take mathematics as well; girls, sometimes.

In the Sixth Form, the formal teaching common in the Upper Middle Forms is no longer necessary to the same extent. The training in method that has already been given ought to have prepared the way for the boys and girls now to digest much stronger fare. Lectures are no longer entirely out of place, especially in the second year of the Sixth Form course. Laboratory directions may be given in much less detail, and, generally, the pupils may be thrown very largely on their own resources. Sometimes they may profitably read up a new topic for themselves, different books being suggested in order that the topic may be approached from different angles; at a later stage one or more teaching periods may then be devoted to discussion. But the method to be adopted must usually depend on the particular subject taken up. Sometimes one or more lessons of the type nominally taken in the Fourth or Fifth Form may be advisable, a new topic proving so difficult that it is best dealt with step by step at the demonstration table, the succession of experiments performed there by the teacher demanding from the pupils close observation and careful reasoning. Sometimes an ordinary lecture may be sufficient. Sometimes the pupils may be sent straight to the laboratory, there to wrestle in pairs or in small groups with the new work. In short, from the teaching point of view Sixth Form work will be of a very varied character. It may happen that half a term will be devoted to a series of experiments, and then a week or two to discussions, to clinching arguments, to generalizing experimental data, to establishing principles, and so on. In the case of chemistry, all pupils will, normally, pursue the same laboratory course, and the subject be developed step by step as in the Middle Forms. In the case of physics, the limited equipment will generally make it necessary for several different types of experiments to proceed simultaneously. There is a difference of opinion

as to the best method of attacking the theoretical side of a subject, and of making the best use, to that end, of the pupils' experimental results. If the pupils' laboratory course is designed merely to verify principles previously demonstrated at the lecture table, the value of the course is trifling; there is then nothing for the pupils to do but what they have already seen done; their hands are engaged but their brains are idle, and the work is unworthy of them. There are, however, certain types of experiments which demand much ingenuity to carry out, even if they have been seen carried out by another person, experiments in which the brain has to help the hand in no small degree, unless failure is to result. The essential point is that during a lesson, whether at the demonstration table or in the laboratory, the learner must never become mentally stagnant.

In all Sixth Form work, a high standard of accuracy and thoroughness should be consistently demanded.

Pupils who take biology as a main subject must certainly take chemistry as well, and physics ought to be included too. It is commonly forgotten how largely physics enters into the study of chemistry and biology. Consider, for instance, such a simple yet fundamental principle as fluid pressure, which is at the bottom of all sorts of chemical and biological experiments. A similar remark applies, in fact, to fundamental physical principles generally. In all schools, *weak physics invariably connotes weak science* all round. Physics, in its turn, is based on mechanics, and, unless elementary mechanics is well taught, the physics is bound to be weak. How, for instance, can a boy understand the action of a galvanometer unless he has previously studied the parallelogram of forces? So generally. It is needless to point out that mechanics, in its own turn, is based on mathematics. There is a natural sequence in all those things that is clamant for recognition.

It all comes round to this: that if a Sixth Form girl takes biology as a main subject, she must have at least an elementary knowledge of mathematics, mechanics, and physics, and must take a fairly substantial course of chemistry concurrently with

the biology. A biologist weak in chemistry or physics is a poor thing indeed, for the study of function except in a very superficial way is beyond him.

We shall return to specialist Sixth Form work in a future chapter.

Non-specialist Sixths

Boys and girls on the non-science side of the Sixth Form, those taking classics, history, and modern languages, will have little time for science, but they ought to give up to it two or three teaching periods a week. Otherwise, they will on leaving school be ignorant of many of the great things that the world are interested in and talking about, the things on which future civilization largely depends. This remark also applies, in no small measure, to those Sixths who are specializing in science; the little physics and chemistry, and it may be biology, that they can do in two years is, after all, a mere drop in the ocean of knowledge of science, and their specialized course needs supplementing, if time can possibly be found for it.

Thus the whole of the Sixth Form might devote, say, two periods a week to science of a more general type. There is admittedly no time for much laboratory work. Most of the ground covered will be covered in the form of lectures, supplemented by directed reading. The lectures should certainly not be of the " popular " lecture type. They must be worthy of intelligent and well-trained boys and girls. They must be given by thoroughly competent teachers, well versed in the subject they lecture on; teachers with a broad outlook, and abreast of modern research. The lectures should not be discursive or fragmentary; evidence should be marshalled, and reasoning from that evidence should be rigorous. " The lectures must stretch the wits of the cleverer boys."

Such lectures should deal with scientific questions of general interest. In their report, the Prime Minister's Committee suggested that the following subjects might meet the case, though it was not intended that all the schools should adopt the same plan:

1. Cosmical physics and the principles of astronomy.
2. Physiology and hygiene; bacteriology.
3. Physical meteorology; weather mapping.
4. History of astronomy.
5. History of mechanics.
6. Development of scientific ideas—constitution of matter, conservation of energy, evolution, heredity, immunity.
7. Lives and work of great workers in science.
8. Bearing of science and invention on industrial progress.
9. Internal-combustion engine; the dynamo.
10. The method and philosophy of science, historically treated.

One or two of these courses might be done fairly exhaustively. Alternatively, half a dozen lectures on the subject-matter of each course might be given, and the boys be thus provided with a large number of topics to think and read about. Experiments to establish, to elucidate, or to illustrate principles should be arranged for whenever possible; and pictorial illustrations, slides for the lantern and for the microscope, and photographs should be at hand. There must be plenty of private reading, and some essay writing. In some schools, the boys themselves give such lectures, sometimes out of school hours, and give them extraordinarily well. And why not? The important thing is that the lectures must be something hard to bite at. They are valueless if they are of the type of popular press articles, served up as garnished tit-bits from nature's lavish larder. A Sixth Form boy wants his teeth sharpened, not his palate tickled.

Time Allowance

The minimum time allowance, suggested by the Prime Minister's Committee, for the science course preceding the School Certificate examination was four teaching periods a week in the first year and six teaching periods a week in each subsequent year. With less time than this, the course of instruction is likely either to be inadequate or to be treated superficially. The division of time between the lecture-room and the laboratory does not much matter; that depends on

the adopted method, and on the man. It is, however, difficult to spare so much time for science in most girls' schools, especially if the bulk of the teaching has to be done in the mornings, though happily the signs of the times are that the number of subjects taught may be gradually reduced. In the Sixth Form, much more time than that just mentioned will be given up to science by those who are specializing, probably half the whole working week, in addition to another quarter for mathematics. A great deal of time is required for laboratory practice in physics, chemistry, and biology. The classical and modern studies sections of the Sixth require, in their turn, three-quarters of their time for their own special subjects, and they are lucky if three periods a week can be spared for science.

In the forms below the Fifth, time is sometimes lost through overlapping between science and geography. The teaching of the principles of physics and chemistry is the business of the science teacher; the teaching of the application of these principles to geography is the business of the geography teacher. Time is also sometimes lost through the overlapping of science and mathematics. Preliminary physical measurement should be included in the mathematical course; so should the nature and the plotting of the commoner forms of graph; a science teacher giving a lesson on, say, Boyle's law ought not to be held up because his boys do not understand the meaning of inverse ratio. Time for mechanics in the Upper Middle Forms can often be spared from the time given to mathematics; the mathematics is strengthened rather than weakened if this is done. The time sometimes virtually wasted by keeping mathematics and mechanics in separate compartments, taught by different teachers, might well be spared for biology.

Time is often lost in the laboratory, especially at the beginning and at the end of a lesson. This is invariably due to faulty organization, not infrequently over such points as the distribution of apparatus and the provision of suitable laboratory directions. Then, again, laboratory periods are sometimes too short, and quantitative experiments are not finished, with the

consequence that the lesson loses the greater part of its value. The copying up of laboratory notes is another common source of wasted energy. The notes written up at the time of the experiment should be final. Copied notes are never faithful records of what has been done.

Directed Reading

Of course laboratory notes and lecture-room notes are altogether insufficient to be representative of the whole of the subject taught. Let the pupils *read*, and teach them how to read effectively. Encourage the Sixth Form to read the original records of some of the great pioneers of science. Help all the boys to acquire the *art* of reading. Let the old catch-words, " weigh, weigh, weigh ", give place to " read, read, read ". That weighing and measuring is the very life-blood of scientific method is, of course, true, but let the boys know all about the *thing* they are measuring and weighing. Too, too often, physics is treated just as if it were mathematics; a boy takes readings mechanically, settles down to arithmetic and algebra, and labels his work " physics ". I have known boys complete a course on " light " without reading any book on the subject save one on " geometrical " optics. When " light " is thus regarded as just an affair of symbols, it is indeed reduced to darkness.

Make the boys *read*; and provide them with books to read.

CHAPTER VIII

Lower Form Science

Nature Study

We have already said that, until 12 or 13, boys and girls are not old enough to face the difficulties of a formal training in physics and chemistry, and that nature study, which in some form is often begun at the age of 7 or 8, may be profitably continued in its broader aspects until at least 11 or 12, and include physiography and astronomical phenomena; also that a good deal of preliminary work may be done in the laboratory at this stage, especially work of a manipulative character.

To be effective, nature study must be a study of the real thing, and not of blackboard sketches however cleverly these may be drawn. The teacher must be something of a born naturalist, must have a good stock of first-hand knowledge, must be an enthusiastic observer; and if he is a collector, so much the better. If he has to train himself, he should read the books of well-known naturalists and acquaint himself with their methods. Gilbert White's *Natural History of Selborne* is still a classic. This and Darwin's *Earthworms*, Lubbock's *Ants, Bees, and Wasps*, Professor Miall's books, and a score of others mentioned in the library catalogue of the Science Masters' Association, should be on the shelves of every teacher taking nature study.

The study of the living plant will naturally occupy a foremost place, and lessons will often be given in the school garden or field. The type of work to be done will largely depend on the season. Seed germination and bulb-growing should form the basis of a good deal of preliminary work. Visits should be paid to the field, the hedgerow, the orchard, the heath, and the marsh, and wild flowers classified. In a town, the local parks must serve, though distant rambles can

often be arranged. In the country there are greater opportunities: I have known highly profitable visits paid to a farm, for the purpose of studying tillage and harvesting operations. The soil may form the subject of several lessons; for instance, plants that thrive in a heavy soil, in a light soil, or in a chalky soil, may be sought and classified. The formation of mould is an allied subject. A visit to the local nursery is almost always welcomed by the owners; it is a good advertisement for them. Much may be learnt there about trees and shrubs as well as cultivated flowers.

Make the young children really keen on the school garden.

Do not forget that nature study lessons should almost always be given *out of doors*, and this is often possible even in the winter. Even during a fall of snow, the children, equipped with hand lenses, may be given an impressive lesson on the geometrical shapes of snow crystals, examined on the dark coat-sleeve. Or a winter lesson may be given on naked trees; for instance, the form of a silver birch from base to crown, its branches and twigs and the sky behind the tracery; the stout and rugged oak, the pyramidal larch, the conical fir, and so on. The barks of trees make another interesting lesson: the corky bark of the elm, the silvery bark of the birch, the smooth olive-grey bark of the beech, the fissured bark of the oak and elm: how beautiful they all are. The age of a Scotch fir as inferred from its mode of new branching in the spring is another subject for an interesting lesson. But there is so much to teach in the spring, when nature wakes up from her sleep, that the trouble is to find time to do it all. Let the young children learn how to use note-books: their observations they should jot down on the spot, and make sketches; these can be worked up into material for a future composition lesson.

But the children's keenest interest is always shown in connexion with the study of animal life. Every school should possess one or more vivaria—an aquarium,* a terrarium, a ranarium, a formicarium, and perhaps an aviary. (I have seen

* For a suggestive article on the construction and stocking of a school aquarium, see *The Times Educational Supplement* for Feb. 17, 1928.

only one school snaillery, and I felt rather doubtful about its educational value.) Children take a delight in watching animals' movements, and a moving thing naturally tends to quicken their powers of observation. In boarding schools, boys often keep their own pets, and in this way collective enthusiasm is often aroused, and a great deal of first-hand information gleaned. Then, again, lessons on spiders and their snares, on silk-worms, silk-spinning and silk-weaving, on the life histories of selected insects, and on dozens of other equally interesting topics, may be included. A school with access to the sea has opportunities for studying crabs and lobsters, star fish and sea-urchins, bivalves and univalves, and other forms of marine life too numerous to be mentioned.

London schools have the Zoological Gardens, the Natural History Museum, and Kew Gardens at their disposal, and willing expert guides may, for the asking, be obtained on the spot. A visit to the new aquarium and the new reptile house at the "Zoo" is a life-memory to a young visitor.

Nature study is a term more comprehensive than is always remembered. It includes, for instance, a great deal of what is commonly called "physiography". Thus "water and its work" suggest considerations of evaporation, clouds, condensation, rain, hail, snow, and ice; springs and rivers; the uses of water to man; and so on: all such topics lend themselves to an elementary treatment of an interesting character. A good deal of elementary astronomy is also within the range of young children: the earth as a planet; day and night; the seasons; the sun and moon; a few of the chief constellations and of the easily recognizable stars; and so forth.

Of course set "lectures" giving mere information in a didactic manner should never be a prominent feature of such elementary work. The main thing is to cultivate the children's power of observation and to teach them to collect first-hand evidence. But lectures should not be ruled out altogether. I have heard teachers give lectures to young boys both at the "Zoo" and in the Natural History Museum, lectures of a strikingly interesting character. With such fine collections to

discourse upon, why should we object to the lectures? Always remember that young children thirst for knowledge. Encourage them to read about natural phenomena beyond the reach of their personal observation.

The number of books published on nature study, especially on the natural history side, is so great that a selection is difficult to make. The selection appearing in the library catalogue of the Science Masters' Association may, however, be recommended without reservation. Amongst newer books the teacher might consult one of a particularly suggestive character, namely, Boulenger's *Animal Mysteries* (" night-lights ", " weather prophets ", " animals and music ", " freaks ", " uninvited guests ", " pugilists ", " architects ", " anglers "); and the same author's *Aquarium Book*, and *The Naturalist at the Zoo*, should be available for pupils.

Elementary Physical Science

Young children are constantly asking questions. It is " how " and " why " all day long. They are eager to know how everything works, and the wise teacher turns to account this natural curiosity. It is an excellent thing to introduce a boy to experimental science, say at about the age of 11 (perhaps at 10, but rarely before this), by giving him a simple machine of some sort to take to pieces,* it may be an old clock. He soon discovers the object of the toothed wheels, how the wheels are pulled round (by weights or by springs), and how the pulling is checked. He can now understand gearing, how to read meters, and so on. In fact, with very little help he learns a good deal about the simple " machines " of mechanics. The mechanism of a gramophone is rather too elaborate for a small boy, and the spring is too stiff. But a common lock he can take to pieces and examine, also a bicycle, and perhaps a sewing-machine or an old musical box. A first lesson on the balance might be followed up by a lesson on the steelyard and an introduction to the lever. The idea of friction may be

* Cf. p. 36.

introduced by telling boys to open a stiff drawer, or to draw back a rusty bolt; they can then learn about the effect of lubricants, and be told something about brakes. They probably know the bare facts already, in which case the facts can be added to and stated more precisely. Such a topic as the centre of gravity may be introduced by getting from the boys all sorts of illustrations from everyday life; the boys need be told but little, except by way of a formal summing up at the end of the lesson. It is a great thing to let a small boy think that *he* is providing the facts, and that his teacher is playing the part mainly of a listener and a looker-on. Do not worry about quantitative work at this early stage, unless the arithmetic is of the very simplest.

Ask a class of young boys how a builder hauls up (1) a heavy weight, (2) a light weight, to the top of a building. One or more of them will almost certainly be ready with the facts, and the essential difference between a pulley-block and a fixed pulley (as in the case of a roller blind) may then be discussed. By means of such simple illustrations a knowledge of the simple " machines " of mechanics may be carried another stage forward, though formal mathematical statements must wait.

Then much useful preliminary work may be done in connexion with liquids. The measuring jar may be used for measuring the volumes of solids. The use of the burette may be taught. The U-tube serves as an introduction to the principle that water finds its own level, and an elementary study of the school water-supply may follow as an application; a first idea of the measurements of the force with which water issues from a tap may also be taught. Flotation, and the action of a ball-tap may also be considered, but let the principle of Archimedes stand over. First notions of air pressure may be given, and the principles of the barometer then touched upon; but do not bring in the aneroid as a sort of corollary—the difference is fundamental. Read that sound old book, Todhunter's *Natural Philosophy*, for useful hints on the treatment of everyday phenomena, treatment without formalism. Most

boys can understand the general action of a garden syringe, a common pump, a diving-bell, a pop-gun, balloons, a parachute, a bicycle-pump, a rocket, a spray-producer, a sucker, a common air-pump, a bellows, but of course the explanation must be kept within the necessarily limited range of their knowledge, and always illustrated by experiments that may be understood. The fire-engine is a little too difficult for young pupils to understand; so, of course, is the airplane.

First notions of the subject of heat may also be included, especially the sections on expansion and thermometry. But "coefficients" should play no formal part here. A boy is always interested in the general method of measuring a small increase in length; he sees at once that a screw of $\frac{1}{10}$-in. pitch, if turned through an angle of $\frac{1}{100}$ of a rotation, must move forwards (or backwards) $\frac{1}{1000}$ in. Thus he may be given the general notion of the method of determining a coefficient of expansion, but he should not be worried with hard terms or with arithmetical problems—unless, at least, these are very easy. Make the boy understand the physical thing and the physical action. Let the mathematics wait.

A little work on change of state, on conduction, on radiation, on absorption, may also be included, but only in the form of simple qualitative experiment and inferences therefrom. The heating system of the school is one obvious thing to utilize for a lesson in a preliminary heat course, though, naturally, only first general notions can be taught.

The subject of light will probably be omitted altogether, unless the pin-hole camera and what it teaches be made the subject of a lesson, perhaps photometry the subject of one or two more lessons, and perhaps the common convex lens as a burning-glass and as a magnifying glass the subject of another. Even the first notions of refraction are, however, difficult for young beginners to understand, and reflection can be touched upon only very superficially. But in any general elementary science course for boys between 12 and 13, the first notions of an electric current should always be included —how a current may be produced, and how its effects may

be shown. I have known a boy as young as 10 give a really intelligent account of an electric bell—intelligent because it was *not* given in the jargon of electrical terminology.

At about 12, a beginning may perhaps be made with chemistry, but this will always be of a very informal kind. An examination may be made of such common substances as sand, lime, chalk, alum, salt, soda, nitre, magnesia, borax, Epsom salts, Glauber salts, sugar, starch, oil, bone, the commoner metals (including alloys), charcoal, alcohol, and turpentine, and *accurate descriptions* written. But the descriptions must be according to plan. The boys must be taught what to look for, and *how* to describe. The action of heat on some of the substances, and the way in which water affects others, make useful experiments of a simple kind. The bunsen burner and flame may also be included in a beginner's course. On the whole, however, it is not advisable to attempt much chemistry. What is done should be done with the object of affording opportunities to the pupils to learn how to describe things, and how to describe changes in things (produced by heat and perhaps by the common acids) accurately and clearly. *This is an essential part of any preliminary training in science.* Teach the pupils to experiment with small quantities of a substance. Teach them to make their own small bulb-tubes and to use them for heating substances.

The science before 12, be it nature study or be it general elementary science, should be, before all things, *a training in observation and a training in accurate and clear description.* Such training is easily possible. But training in rigorously exact inductive reasoning is not possible at such an early stage. And, in science, reasoning is mainly inductive in character. This is not merely a matter of tying up bundles of facts. Something outside the facts has to be supplied by the mind, and that is, as a rule, much too difficult for beginners. If, by the age of about 12, boys have been trained to observe and to describe in accurate language what they have observed, the way is paved for more exacting work. Hypotheses and laws are matters for minds rather more mature.

On the whole, the best plan is probably to confine the work up to 11 to plant and animal life, and simple physiography; and from 11 to 12, or a little later, to continue this work and to supplement it with introductory physics and chemistry.

It is advisable to warn children that nature study must not become nature pillage. As collectors, children are apt to be ruthless.

CHAPTER IX

Syllabuses and Schedules of Work

Examiners' Syllabuses and Teachers' Syllabuses

We have already pointed out that a science syllabus drawn up by an examining body does not pretend to be anything more than a number of topics on which questions may be asked. No attempt is made to arrange the topics in the order in which they are best presented to a class. A teacher will cast his eye over it, and so get a general idea of its scope. He will then sit down and draft an independent teaching syllabus for himself, logically arranged in such a way that foundations and principles may be established, points of theory worked out, and applications to everyday life included. The many gaps in the examination syllabus should thus be filled up, for although the examiner will not ask questions on the subject-matter that now fills the gaps, this subject-matter is essential to the rational development of the course of work.

Sometimes syllabuses or schedules of work are published with the intention of showing what subjects of science might be included in a school course if the school could be freed from examination requirements, but these also are generally unsuitable for a teacher to adopt without rearrangement and expansion. Such syllabuses are occasionally drawn up by

committees or individuals specially asked to draft courses of instruction to meet some particular need: it may be a course of a more comprehensive character than that usually taught, it may be a course which claims to lend itself to improved methods. Sometimes these courses are fruitfully suggestive, even when they do not square sufficiently with the needs of public examinations to make their adoption generally possible. Here is such a syllabus of a three-years' course drawn up by Sir A. D. Hall, who says: " the spirit in which this course should be pursued renders it very unsuitable for formal examination ".

Sir A. D. Hall's Three-years' Course

First Year, First Term. Properties of Matter:

Solid, liquid, and gaseous states.

Density. Identification of materials, e.g. gold, by density determination.

Electricity. The pendulum: determination of time. Galileo.

Liquid pressure. Archimedes. Flotation. Surface tension.

Pressure of a gas. Barometer. Boyle. Pumps and siphons. Diffusion of a gas.

First Year, Second Term. Chemistry:

Burning and the products of combustion. Chemical change. Air and oxygen.

Priestley and Lavoisier. Metals and their oxides. The conception of elements and compounds.

Hydrogen. Water. Cavendish's experiments. Solution.

CO_2. The isolation of carbon, and its presence in many compounds.

Chalk and lime. Black's work. Mortar and cement.

Nitrogen, ammonia, nitric acid. Rusting and corrosion.

First Year, Third Term. The Life of a Plant:

Structure of a seed. Germination.

The leaf. Transpiration. Photosynthesis. Storage organs.

The root. Root hairs. Absorption of water.

Nutrition. Constituents essential to nutrition.

Flower and seed. Adaptation of plant structure to environment.

Second Year, First Term. Heat:

Expansion by heat. Thermometry.

Distinction between temperature and quantity of heat. Specific heat.

Evaporation. Cooling by evaporation.

Vapour pressure. Relation between boiling-point and pressure.

Heat and work. Cooling by expansion of gases. Mechanical equivalent.

Second Year, Second Term. Physics:

Magnetic bodies. The magnetic field.
Electric current. Faraday's experiments.
The simple dynamo.
Electrical current produced by chemical action.
Potential and resistance.
Electrolysis as a reversal of the action of a battery.
Equivalences in electrolytic action.
The principle of the conservation of energy.
Connexion between voltaic and static electricity.
The nature of a wave. Wave transmission.
Sound as a vibration. Pitch. Harmonics.
Light as a wave motion. Reflection.
Refraction. The prism. Colour. Simple lenses.

The teacher may approach electricity by way of current or by way of the electron.

Second Year, Third Term. Zoology:

A broad outline of the animal kingdom. This course should make the pupil acquainted with some of the leading differentiæ between the main groups of animals, and should introduce him to the idea of species and classification. Economic considerations should be kept in view. It is desirable that every pupil should dissect one animal, e.g. a rabbit.

Some teachers may prefer to take the physiology course prior to the zoology.

Third Year, First Term. Chemistry, second course:

Carbon as the basal element in the compounds elaborated by living organisms.

Linkages in carbon compounds. Homologous series. Isomerism.

Alcohol, aldehyde, acetic acid.

Sugars and other carbohydrates.
Enzymes. Diastase. Alcoholic fermentation. Brewing.
Yeasts and bacteria.
The proteins and their hydrolysis by enzymes.
Colloids and crystalloids.

Third Year, Second Term. Physiology:

Circulation. Respiration. Breathing as a form of combustion.
Muscle. Combustion as the basis of work done by the muscle.
Digestion. Food values.
Energy requirements of man; variation with work.
Nitrogen metabolism and tissue repair. Elimination of nitrogenous waste.
The nervous system. The brain and conscious nervous actions. Reflexes.
(The cell theory. Somatic and gametic cells. Reproduction.)

Third Year, Third Term. Botany, second course:

Asexual reproduction of plants: cuttings, grafts, buds, bulb offsets, &c.
Fertilization. The seedling as a new individual. Variation in seedlings.
Species and varieties.
Varieties as a fact. Distinction between congenital and non-heritable variations.
Outline of the theory of natural selection. Inheritance of unit characters.

The course preserves a proper balance amongst the claims of physics, chemistry, and biology. It may be regarded as a sound general elementary course, though, for teaching purposes, a certain amount of "filling up" would be necessary. Indeed, this is implied by the course itself. Unfortunately it does not quite meet the needs of the requirements of the School Certificate examinations.

"Science for All"

Another scheme of work which, like the preceding, gets right away from examinations and is refreshingly suggestive, was drawn up, towards the close of the war, by a committee specially appointed to describe the sort of science teaching

which is suitable to form an essential part of a liberal education, and to report on the scope and nature of "Science for All" in Public Schools. In the report the aims of the science course to be adopted are stated to be: (1) training in scientific method by experimental investigation; (2) conveying useful information and fixing it by practical exercises; (3) humanizing the work as much as possible by using daily-life phenomena, practical applications, machines, agricultural processes, &c., as the material.

"Within the above principles, complete freedom should be left to the teacher in accordance with his interest and opportunities. He should arrange his own courses, syllabuses, &c.; decide what material he employs for any of the above objects, and whether he achieves them by 'object', 'subject', 'problem', or any other method." "The main headings that the science should include are given: *for convenience* these headings are grouped under the conventional subjects. But it is the humanizing method that is the vital point."

Then follow numerous headings, with topics worked out in considerable detail. When drawing up a science course, a teacher may usefully consult this report. He should not *adopt* any of the prescribed syllabuses, any more than he should adopt ready-made syllabuses from any other source. But the report* is so full of useful hints that every teacher should read it.

"Educational Pamphlet 17"

This is a Report on Science Teaching in English Public Schools, edited by Mr. O. H. Latter, and published by the Board of Education in 1909. It contains a good deal of useful information concerning science teaching, and Appendix II contains schedules of work from six selected schools. All these schedules are worthy of close examination. In particular, the reader should pay careful attention to schemes for schools "D" and "E". The former is a physics scheme, with a

* The Report is signed by Mr. Eggar, Mr. Oldham, and Mr. Vassall. The price is 6*d*.

carefully graded course of work, extending over four years, in seven branches of physics, viz. mechanics, hydrostatics, light, heat, sound, magnetism, voltaic electricity, and frictional electricity. The latter is a biology scheme (with further schemes in physics and chemistry) of quite exceptional interest.

The Preparation of a Teaching Syllabus

The preparation of a satisfactory working teaching syllabus is no easy task, especially if the needs of external examinations have to be borne in mind. But success depends so much on the way in which a course of instruction is approached and developed, that it is scarcely possible to give too much care to working the course out.

One of the first difficulties will be to decide how and where successive points of theory shall be established. But as in nearly all cases these will not be touched upon until accumulated experimental data demand generalization and the formation of hypotheses, the main sequence will be pretty obvious. For instance, no attempt may wisely be made to establish the Law of Multiple Proportion until a considerable amount of definite and satisfactory quantitative experimental work has been done with one or more groups of allied oxides. Generally, principles will be established simply and solely as the logical consequences of generalizations necessarily derived from accumulated quantitative results. It is a safe teaching rule to let all theory stand over until previous experimental work actually calls for it. With an experienced teacher, there would be exceptions; but the young teacher should always regard such exceptions as a source of possible danger.

There is a kind of natural sequence in the selection of successive topics that probably no teacher could overlook. For instance, it would be practically impossible to deal with the action of the voltaic cell, or with the photosynthesis of plants, until at least a preliminary course of elementary chemistry had been completed; or to deal with the galvanometer, before some knowledge of the parallelogram of forces had been

acquired; or with the barometer, before elementary hydrostatics had received attention; or with corrections for temperature and pressure in experiments with gases, until the barometer, the thermometer, and coefficients of expansion had been considered; or with the kinetic theory of gases, before touching upon momentum and energy; or with the intensity of a magnetic field, without some previous idea of force and its measurement. These and a large number of other points of like character will always compel the teacher to adopt the same general sequence, though in detail the sequence need not follow any particular prescribed form.

The following teaching syllabus in chemistry was sent to me by the late Professor Alexander Smith, whose authority as a teacher of the subject carried great weight in the United States and Canada during the earlier years of this century. He told me that it had been used with marked success in many American schools. English teachers who have used it have told me that their pupils have obtained a particularly clear knowledge of chemical theory, successive hypotheses being logically established and the whole body of theory being built up step by step. This is undoubtedly the outstanding feature of the syllabus. Nowadays it would be severely criticized because of its exclusively academic character. Far too little attention is devoted to the applications of chemistry and to the chemistry of everyday life. But from the point of view of the logical development of chemical theory, it leaves little to be desired.

The course is preceded by the usual preliminary course of physics, including Boyle's law, expansion, the physical properties of gases, calorimetry, &c. But certain points in physics are revised when found necessary, as will be seen.

A Teaching Syllabus in Chemistry

In the earlier portion of this course all formulæ and equations, all ideas of molecules, atoms, and atomic weights, should be avoided. Principles must be established from purely experimental observations. Theories should be introduced with

extreme caution. A knowledge of the atomic theory is quite unnecessary in the earlier stages, even if its introduction during those stages could be justified.

The *earlier generalizations* will be mainly of a qualitative nature; for example:

1. Chemical changes are accompanied by an alteration of physical properties.
2. There is a production or a disappearance of heat.
3. There is a necessity for contact; a fine state of division is advantageous.
4. There is an increase of speed with an increase of temperature.
5. Changes are often more easily effected by dissolving substances in water.

The whole of the early work should be designed to give a knowledge of *method*. Much of it will therefore be thrown into the form of problems. For the solution of these, the teacher will provide definite laboratory instructions, which, however, must never be so full as to tell the pupil anything that he can reasonably be expected to discover for himself.

The larger proportion of the easier experiments will be performed by the pupils. As the pupils acquire more and more skill, more and more difficult experimental work may be required of them. But certain types of experiments will necessarily always be performed by the teacher himself.

1. Examination and accurate description of common substances: for instance, sand, lime, limestone, chalk, marble, alum, common salt, soda, nitre, magnesia, borax, iron pyrites, gypsum, Epsom salts, Glauber salts, sugar, starch, fat, olive oil, turpentine, the commoner metals, different woods, charcoal, coke, coal, alcohol, vinegar. The obvious properties of these substances and the principal uses. (It is essential that pupils should be *taught how* to describe things systematically.)
2. Common laboratory operations, e.g. decantation, filtration, evaporation, distillation.

3. Action of heat on some of the substances above named, and how they are affected by air and water.—Elementary notions of burning.

4. Alteration in weight of common substances when heated. —Gain or loss?

5. Examination of ordinary tap water.—How to purify it. Amount of air dissolved in water and how to measure it.

6. Study of the rusting of iron.—Iron not affected by pure water or dry air. (The reasoning underlying the investigation of this problem is generally very faulty.)

7. The Common Metals.—Experiments to show malleability, ductility, &c. Relative densities: find, and tabulate. Metals good conductors of heat. They combine with an active constituent of the air to form a new substance called oxides. Show formation of iron scale, copper scale, litharge, magnesia, zinc white, &c.

Iron.—Show cast iron, wrought iron, steel. Differences and properties. Uses. Action of hydrochloric and sulphuric acids on iron.

Copper.—Properties. Uses. Easily attacked by acids. Verdigris.

Lead.—Properties. Uses. Why used by plumbers? Slowly acted on by common water: consequence? (The SH_2 test will come later.)

Silver.—Properties. Uses. How blackened by coal-gas or smoke.

Zinc.—Properties. Uses. Action of acids. Galvanized iron.

Tin.—Properties. Uses. Tinned iron (" tin ").

Common *alloys*: brass, bronze, pewter, solder. Coinage and jewellery.

8. Crystallization.—Efflorescence and deliquescence. Make soda and alum crystals. Prepare zinc sulphate crystals by dissolving the metal, the oxide, and the carbonate in sulphuric acid. Identify the same substance in each case, and note percentage amount of water of crystallization in each case.

9. Acids and Alkalis.—Neutralization. Salts and their formation. General action of dilute hydrochloric, nitric, and sulphuric acids on the commoner metals and the oxides of metals. Tabulate the results.

At this stage the more systematic study of the subject will begin. The work will be mainly quantitative, and data will be gradually

accumulated for the purpose of establishing the more elementary principles of the theory of Chemistry.

10. Find the weight of a litre of air. Determine the coefficients of expansion of air (constant pressure and constant volume). Reduction to N.T.P.

11. Oxygen.—Preparation, Properties, Identification. Common oxides. Weight of a litre of oxygen. Amount of oxygen obtainable from mercury oxide and potassium chlorate.

12. Hydrogen.—Tests. Properties. Identification. Comparison with oxygen. Volume displaced by zinc and by magnesium. (Volume, thence weight.) The product formed by burning hydrogen.

13. Water.—Produced by burning hydrogen in air or oxygen. Properties. Familiar facts. Composition: (1) *Synthesis*—pass hydrogen over red-hot copper oxide; ratio of weights of hydrogen and oxygen; (2) *Analysis*—by electric current; ratio of volumes of hydrogen and oxygen. Now the relations between the composition by weight and the composition by volume. Elements and compounds defined.

14. Make magnesium oxide by calcining the metal, also by oxidizing with nitric acid. Identify the same product in each case, qualitatively and quantitatively.

Now collect up the results of the various quantitative experiments performed, and establish the generalization of *Definite Proportions* by weight.—Even the *smallest conceivable portions* of a compound must contain its constituents in definite relative proportions. Every body is supposed to be made up of such little masses, called *molecules*. Refer to the electrolysis of water, which shows that the molecules are broken up. The smallest portions of oxygen and hydrogen in the molecules are called *atoms*.

15. The volumetric composition of water, showing the condensation from three volumes to two.

16. Nitrogen.—Preparation from the air. Physical and chemical properties.

17. Atmospheric Air.—A *mixture*. Proportion of oxygen to nitrogen. Proof of presence of water and carbon dioxide in air.

Diffusion of gases. Respiration. Ventilation. Mutual action of air and plants.

Relation of weight of air to weight of its constituents. (Cf. the densities of oxygen and nitrogen with the density of air.)

18. Quantitative Research on Chalk.—Chalk, limestone, quicklime, lime water, slaked lime. Volume and weight of carbon dioxide expelled from chalk. General quantitative inter-relations amongst the different substances. (The success of this research depends very largely upon the laboratory directions supplied to the pupils.)

19. Hard and Soft Water.—Methods of softening. The study of washing soda. Familiar facts.

20. Carbon.—Its different forms; allotropism. Its presence in organic substances. Carbon dioxide; the lime-water test, and further study of the white precipitate. The common carbonates. Relation of washing soda to caustic soda. Action of alkalis on grease.

Carbon monoxide: preparation and properties.

The quantitative relation between the two oxides of carbon.

21. Combustion.—Flame. The phenomena of burning. Products of combustion—water, carbon dioxide, and perhaps ash. Smoke and soot. The use of tall chimneys. The bunsen burner; principle. Luminosity of flame. Lamp chimneys. Reduction. Coal gas and its manufacture. Coal gas and air an explosive mixture. How *not* to seek the source of a gas leakage.

22. Nitric Acid.—Preparation. Properties. Action of the acid on metals. Common nitrates. The acid as an oxidizing agent.

23. Nitrous Oxide.—Preparation. Properties. Distinguish from oxygen. Experimental determination of its composition. Weight of a litre of the gas.

24. Nitric Oxide.—Preparation. Properties. Distinguish from oxygen and from nitrous oxide. Experimental determination of its composition. Weight of a litre of the gas.

25. The Five Oxides of Nitrogen.—Brief comparative study.

(1 part by weight of nitrogen to ·57, 1·14, 1·71, 2·28, 2·85 parts, respectively, of oxygen.)

26. *The Law of Multiple Proportions.*—State, and illustrate with the group of oxides just studied. Verify further, as suitable data are accumulated. Define *combining weights.* Symbols. One or two simple formulæ. Chemical equations, as a shorthand registration of *experimental facts* only. Solution of easy chemical problems.

27. *Equivalents.*—Displace silver in silver nitrate by copper and by zinc; displace copper in copper sulphate by zinc and by magnesium; tabulate the data and the data of former replacement experiments (e.g. of hydrogen in sulphuric acid by zinc and by magnesium), and state and verify the *Law of Reciprocal Proportions.* (These laws cannot be rigorously established from the scanty data available, though the data ought to suffice to verify a formal statement of them.)

28. Elementary Notions of the *Atomic Theory.*—Formulæ and equations cannot yet be used except as shorthand expressions of experimental facts.

29. Acids, Bases, Salts—further notions. Tabulate instances from experimental work already done. Nomenclature of bases and of salts. Hydroxides. Mutual action of acids and bases; products of the reactions.

30. Acidimetry and Alkalimetry.—Theory of neutralization. Solution. Ionization. Double salts. Easy volumetric analysis (advantages compared with gravimetric). Indicators.

31. Chlorine.—Preparation. Properties. Energetic attraction for metals. Weight of a litre of chlorine. Attraction for hydrogen. Bleaching and disinfecting; chloride of lime.

32. Hydrochloric Acid.—Preparation. Properties. Common chlorides. Weight of a litre of the gas. Combination of chlorine and hydrogen—no alteration in volume. Composition of hydrochloric acid gas, using sodium amalgam; composition represented by a formula.—We now know the weight of a litre of (1) hydrochloric acid gas, and (2) chlorine; we also know that hydrochloric acid contains half its own volume of hydrogen. Hence we can deduce the weight of a litre of hydrogen.

33. Ammonia.—Preparation. Properties. Composition by volume. Weight of a litre. Solubility in water. Ammonium salts. Composition by weight (known weight of gas passed over red-hot copper oxide; water and nitrogen collected). From the data thus obtained, calculate the relative *volumes* of hydrogen and nitrogen which can be obtained from ammonia gas; compare with the experimental result of the composition by volume.

34. Revise Boyle's law, and law of Charles; remember that gases agree as regards *physical* properties, however much they differ in *chemical* constitution. Collect up results on *densities* and on *volumes* of gases (water, nitrous oxide, nitric oxide, hydrochloric acid, ammonia, &c.), and so lead up to the *Law of Gay-Lussac.*—Relation between specific gravities and combining weights of gaseous elements.—Revise the work on the composition of water by weight and by volume, and show clearly how the experimental determinations of the specific gravities of (1) water gas, (2) oxygen, (3) hydrogen, help to establish the relation between weight and volume of water gas.

35. We are now in need of *Avogadro's hypothesis.*—For we require an *explanation* of the facts that led up to the Law of Gay-Lussac, and Avogadro's assumption is *one* possible explanation, though it may be superseded by another some day.

36. The atomic theory further developed. The probable explanation of the facts underlying the Laws of Definite, Multiple, and Reciprocal Proportions. The atom, and atomic weight. Relation between "equivalents" and atomic weights. Distinguish between facts, laws, hypotheses, and theories.

37. *Chemical Formulæ.*—By analysis we find that silver nitrate consists of 63·52 per cent of silver, 8·23 per cent of nitrogen, and 28·25 per cent of oxygen (by weight). How the empirical formula $AgNO_3$ may be determined from this analysis. Why we write $AgNO_3$ rather than $Ag_2N_2O_6$ or $(AgNO_3)_n$. Now establish more rigorously the formula of some such compound as ammonia, nitrous oxide, or carbon dioxide, the densities of which have been determined. Distinguish between empirical and rational formulæ. Equations; their precise significance.

We now begin to group together elements and their compounds for systematic study, in accordance with the principles of the Periodic Law.

38. The Halogens.—Revise the work on chlorine; the commoner compounds of chlorine. Bromine and iodine and their chief compounds. Fluorine and hydrofluoric acid.

Comparative study of these four elements. Similarity in their physical properties; similarity in their chemical actions; their combination with hydrogen; progressive diminution of chemical energy with progressive increase of combining weight. Curious numerical relation—the combining weight of bromine a mean between the combining weights of chlorine and iodine. —*A natural group of elements.*

39. Sulphur.—Occurrence in nature. Commercial preparation and forms. Effects of heat; allotropism (compare oxygen and carbon). Solubility. Attraction for metals; sulphides.—Hydrogen sulphide; preparation, properties, and composition; decomposed by salts in solution, yielding sulphides and acids; use.—Sulphur dioxide; preparation, properties, and composition; solution in water; sulphites; bleaching.—Sulphuric acid; properties and uses; manufacture; effect of mixing with water; action on iron and on copper; common sulphates; normal and acid salts; monobasic and dibasic acids.—Selenium and tellurium mentioned.—Comparison of oxygen, sulphur, selenium, tellurium.—*A second natural group of elements.*

40. Revise work on nitric acid and the nitrates.—Phosphorus; manufacture; physical properties; allotropism; phosphorus and hydrogen; phosphorus and oxygen; phosphates; matches.—Arsenic, antimony, and bismuth, briefly.—Comparison of nitrogen, phosphorus, arsenic, antimony, bismuth; chemical resemblances; progressive change in specific gravities with increase of combining weights; progressive change from strong acid to basic character of the oxides, with increase of combining weights.—*A third natural group of elements.*

41. Revise work on carbon and the carbonates.—Silicon; occurrence in nature; silicon dioxide; silicates; glass.—Chemi-

cal resemblance between carbon and silicon.—*A fourth natural group of elements.*

42. *Valency.*—Collect useful facts from old work bearing on the subject. Comparison of the number of combining weights of hydrogen which unite with one combining weight of chlorine, oxygen, nitrogen, carbon; observe that the combining weights of the elements are able to unite with different but definite numbers of combining weights of hydrogen. Valency as a characteristic of a *definite quantity* of an element; how this quantity may be regarded as (1) the combining weight, (2) the atom.—Atomic heat.—Atomic weights generally.—The atomic theory reviewed.

43. The Periodic Law (briefly):—

(*a*) Elements having the same valency agree in other chemical characters also. Hence the elements are found in *natural groups.*

(*b*) The gradation of properties in each natural group is also found to depend on the combining weights.

(*c*) Thus we find that combining weight—the most fundamental chemical property of matter—is the natural basis for the classification of all elements.

(*d*) Show how, by arranging the elements in the order of their combining weights, similar properties reappear at regular intervals.

(*e*) Point out the eight natural groups thus identified, and the gradation of properties in each.

44. Study of a few of the Common Metals.—The power to form basic instead of acid hydroxides is the most distinguishing chemical characteristic of the metals, but the gradation from distinctly acid to distinctly basic properties is unbroken. A logical study of the elements should be based on their natural relations shown by the Periodic Law. The following metals may be selected for study: sodium, potassium, calcium, magnesium, zinc, mercury, copper, silver, gold, tin, lead, iron, aluminium. The study should include the following topics:—

(*a*) The chief physical properties.
(*b*) The principal chemical reactions.
(*c*) The most important compounds.
(*d*) Alloys.
(*e*) Extraction of metal from ores.
(*f*) Useful commercial processes and products.

45. Qualitative Analysis.—So far as this is necessary, it should be made an adjunct to the study of the metals. As far as possible, pupils should be taught to make up their own separation tables. Any intelligent pupil can discover for himself how to separate, for instance, the chlorides of mercury, silver, and lead, if he has been taught to study the chlorides separately. Too often the time spent on qualitative analysis is absolutely valueless, the operations being entirely mechanical.

46. Volumetric analysis further studied, especially in connexion with the theory of solution.

47. More difficult quantitative experiments of a typical nature to verify principles already established. The pupils ought now to have acquired a considerable amount of manipulative skill and to be prepared to perform experiments demanding resource and methods of some refinement.

For Sixth Forms, such a syllabus would have to be extended, probably on these lines:

48. The Periodic Classification: its extended significance. Radioactivity. Isotopes. The modern theory of the structure of the atom.

49. Physical Chemistry.—Solution: determination of the molecular weight of dissolved substances; electrolysis and electrolytic solutions. The rate of chemical change: equilibrium; catalysis; dissociation.

50. Organic Chemistry.—Structural formulæ. The fatty derivatives: general methods of preparation, general properties, and methods of finding the constitution of the simpler paraffins and their halogen, oxygen, and nitrogen derivatives. Mixed derivatives and stereo-isomerism. The aromatic derivatives: benzene, its constitution and the preparation, properties and structure of its simpler homologues and derivatives.

51. Modern applications of chemistry.

An Approach to Botany, Experimentally

The following is an outline teaching syllabus which has been known to work successfully when botany has been developed on an experimental basis. It is assumed that a course of nature study is taken in the Lower Forms, and that the pupils had then acquired a good working knowledge of plants and the parts of plants as things carefully observed; also that the pupils have been through fairly substantial courses in elementary physics and chemistry, the physics including pressures, capillarity, diffusion, osmosis, heat, and the spectrum; and the chemistry including air and water, chalk and the common carbonates; the common acids, oxides, and salts; solution and crystallization; sulphur and the common sulphates; ammonia; the common nitrates; phosphorus; carbon; the solvent action of alcohol; starch and its conversion into sugar; and elementary notions of the atomic theory—enough to enable the pupils to realize the significance of simple chemical interactions, and of starch and sugar relations.

The botany syllabus which follows shows a reasonably logical sequence, but in practice, the topics selected must depend in some measure on the season of the year. And it will often be necessary, at some later stage, to return to a topic left incomplete at an earlier stage because of its difficulty. The necessary experiments are detailed in most of the newer text-books.

THE SOIL

1. What the soil is: a store-house of moisture and plant food.
2. Kinds of soils: clay, sand, loam, gravel, chalk, peat.
3. Soil and sub-soil. Mechanical analysis of soils.
4. Clay: properties. Clay and water. Action of lime on clay.
5. Sand: properties. Relative water capacities of sand and clay.
6. Soil-water: free, capillary, hygroscopic.
7. Leaf-mould. Percentage lost on burning. Humus.
8. Plant food in soil. Sow seeds in a pot of (1) soil, (2) sub-soil, (3) sand. Vary again with moist and dry soil and sub-soil.

9. Dwellers in the soil. Earthworms. Micro-organisms: gelatine cultures.

10. The soil and the plant. Experimental proof that soils can store water. Excess of water means deficiency of air.

11. Cultivation and tillage. Plants need *water*, *air*, *warmth*. Action of frost. Ploughing, harrowing, raking, hoeing, mulching.

12. Field expeditions to study soils and sub-soils.

PLANT FOOD

1. Elements essential for healthy growth. Except carbon, these are absorbed by the roots, usually in the form of nitrates, sulphates, phosphates, chlorides, and silicates of K, Na, Ca, Mg, Fe.

2. Show by water-cultures that these elements are essential. Healthy growth only if solution contains *potash*, *lime*, and *magnesia*, combined with *nitric*, *phosphoric*, and *sulphuric* acids, with the trace of an Fe salt.

GERMINATION

1. Plant seeds in sawdust. Keep some wet, others dry; some cold, others warm; some in the light, others in the dark. Sow seeds in soil at different depths, at different dates. Sow large and small seeds. Tabulate results of differences in yield.

2. Sow seeds in chopped sphagnum, in box with glass side. Note process of germination.

3. Where and how (1) water, (2) air, enter seeds.

ROOTS. PLANT PHYSICS

1. Roots of seedlings. Their behaviour towards moisture, gravity, and light. The clinostat.

2. Determine region of most rapid growth. The growing point. Root-hairs.

3. Diffusion. Illustrate by experiments with blue litmus and acid, copper sulphate and water, alcohol and water. Laws of liquid diffusion. Colloids. Dialysis.

4. Osmosis. Dry raisins in water swell up; fresh grapes in strong sugar solution shrink. Experiments to show diffusion of sugar solution through bladder or parchment with water. Effects with more highly concentrated solutions and at higher temperatures. Experiment to show osmotic *pressure* by rise of column of water in tube. When diffusion necessarily stops.

5. Turgidity, i.e. osmotic pressure regulated by the influence of

the protoplasmic layer. Experiments with pieces of beetroot and with strips of dandelion stem. Cf. stiffness of root-hair with stiffness of inflated bicycle tyre; pressure in root-hair due to absorption of water. Why this absorption? In root absorption, a large quantity of hygroscopic water with dissolved salts passes into root-hair.

6. Elementary notions of the cell as an osmotic apparatus.

7. The various forms of roots.

STEMS AND BUDS

1. Place cut twigs in coloured water. Trace the stained channels.

2. Compare the stained bundles in dicotyledons and monocotyledons.

3. Functions of stems as water-carriers. Vascular bundles in leaves continuous with those in stems: demonstrate.

4. General structure of stem. Growth in thickness; annular rings, rays; hard wood and soft wood; cambium; formation of cork.

5. Modes of branching. Knots in timber.

6. Healing wounds in trees.

7. Formation of roots from cuttings. Budding and grafting.

8. Climbing stems. Underground stems. Spines, prickles, thorns.

9. Buds. Examine brussels sprouts and horse-chestnut buds. Structure and development.

LEAVES

1. Use of the large surface. Structure of veins.

2. *Respiration.*—Absorption of oxygen and giving out of carbon dioxide best shown by germinating seeds. (The reasoning in this experiment is often faulty. See Ganong's method * with the 3 U-tubes.) (Respiration and photosynthesis are antagonistic processes, though the latter greatly predominates: hence difficulty.)

3. *Transpiration.*—Experiments with the potometer. (Transpiration experiments involve no serious difficulty, but reasoning from the results demands care.)

4. *Photosynthesis.*—This is probably the most difficult process to demonstrate satisfactorily, and to reason about logically, in the whole range of Botany. A course of experiments must be carefully planned to show that starch-making cannot proceed in the absence of either light, chlorophyll, carbon dioxide, or water. Tell pupils plainly that we are still uncertain of the mode of the actual synthesis of starch.†

5. Process of nutrition considered as a whole.

* See p. 198. † See p. 200.

GROWTH

1. Growth under varying conditions (temperature, light, moisture, &c.).

2. The auxanometer. Auxographic records and their interpretation.

3. Irritability. Stimulus and response.

FLOWERS

1. The different organs and their functions.

2. Grow sweet peas and show the sub-varieties of colour and shape by selection and cross-fertilization.

3. Experimental study as to the necessity of stamens and pistil if seed is to be produced.

4. Relations of plant to insect life.

5. Experimental study of pollination.

6. Colours and scents, and nectar in flowers.

7. Floral diagrams.

8. A few common orders: two or three in detail, half a dozen others in outline. The use of a Flora. (It is waste of time to devote much attention to mere classification, but the botanist's *principle* of classification must be understood thoroughly.)

FRUIT AND SEEDS

1. What has become of each of the parts of the original flowers, i.e. sepals, petals, stamens, receptacle, ovary, style, stigma?

2. Various kinds of fruit; adaptations for dispersal.

3. Comparative examination of, e.g., apple, cranberry, cherry, orange, grape, banana, strawberry. Classification of fruits. The chief edible fruits and vegetables.

4. Structure of seeds.

TISSUES AND CELLS

1. Epidermal system: continuous over entire plant? Removable? Smooth or with appendage? Any green in the epidermis?

2. Cortical system: continuous over entire plant?

3. Fibro-vascular system: conducting and strengthening; continuous through entire plant (demonstrate). Order of arrangement of bundles in stem, in petiole, in leaf. Branching of bundles.

4. Storage system.

5. Systems of tissues: protective (epidermis, cork); cortex;

strengthening (sclerenchyma); growth (cambium); conducting (sieve-tubes, wood vessels); aeration (intercellular passages and stomata); storage (pith, medullary rays).

6. The cell: cell-wall, protoplasm, cell-sap.
7. Protoplasm: cell nucleus, plastids or chromatophores, cell-plasm or cytoplasm.
8. Cell-wall: thickening, pits, spiral and annular bands.
9. Cell-division.
10. Microscopic examination of tissues.

PLANT ECOLOGY

The external factors of the conditions of the life of plants in nature. Plants associated with heaths, moors, bogs, mountains, sandy districts, chalk downs, maritime regions, sandy beaches and dunes, saline marshes, coniferous woods, woods of beech, oak, &c., arable land, pasture land, ditch sides, ponds, &c.

THE PINE AND THE FERN

Life histories.

ECONOMIC USES OF PLANTS

Timber, cork, fibres, cotton, paper, dyes, tannins, oils, gums, resins, rubbers, starches, sugars, "roots" and "tubers", green vegetables, salads, fruits, nuts, condiments, spices, &c.

Unless botany is taught experimentally, it has little claim to rank as science suitable for schools. Too frequently the work done is purely observational. The great difference between observation and experiment is that the latter implies *control of some of the conditions* underlying a phenomenon. In this way *differences* are established, and these form the very foundation of all scientific reasoning. Mere dissection is not experiment; it is only clearing away obstructions for the purpose of making observations.

It is not intended that any of the syllabuses outlined in this chapter should be adopted for teaching purposes, though they are known to have worked well in practice. They are worth reading through carefully, and pondering over critically.

CHAPTER X

Science Teachers as Teachers of English

Is the Technical Terminology of Science Necessary?

In a particularly suggestive article contributed to *Nature* in February, 1925, the writer said: " We cannot accept for a moment the common belief that writers on scientific subjects compare unfavourably with workers in other intellectual fields in the capacity to express themselves in suitable words, or in their appreciation of good English, and we resent strongly the supercilious attitude which literary people often present towards scientific works."

If, however, that writer will do as I did,* take down *at random* from his library shelves a score of books written by men of science, and examine any page chosen *at random* from any of those books, he will probably have little difficulty in finding at least one sentence incorrectly constructed. It is not a question of such books being obscure to a layman because of the use of technical language; it is rather a question of loose constructions, and of phrases and sentences not free from ambiguity. It is less a question of poor vocabulary than of a failure in nicety of discrimination in the use of ordinary words. The faults are those of an education which was allowed to drift too soon into a specialist channel.

Consider the case of a boy who has obtained a " credit ", perhaps a " distinction ", in English in his School Certificate. Does this connote a standard of English good enough for the future science specialist? Most certainly not. The boy has not reached a stage when he can be said either to express his thoughts clearly and forcibly in written and spoken English,

* See *The Writing of Clear English*, pp. 86–108. The sentences quoted and reconstructed were taken from books selected and opened at random.

or to construct his sentences without any possibility of ambiguity. When science is taken as a main subject in a Higher Certificate examination, the test in English should be exacting, and a failure to pass the test creditably should entail a failure in the whole examination.

We ought always to distinguish between the backward state of technical education and the wonderful success of technical achievement. The great majority of the students in the technical institutions have not received a liberal education, and most of them are therefore likely, on going out into life, to remain hewers of wood and drawers of water. On the other hand, many of the world's great technical successes have been achieved by men who had received the highest possible liberal education before they entered upon a technical career. The greatest technical excellence is usually traceable to an all-round development of the mind and of the personality. Happily there is now a great demand by the technical institutions for students who have received an all-round education, and, at bottom, this means students with some real mastery and appreciation of their mother tongue.

It is a good thing for older pupils to try to understand that there is no necessary divorce between the intellect and the imagination, between the analytical and the altruistic faculties, between the man of science and the poet. Lucretius expounded the atomic theory in one of the finest poems ever written. Even so recent a naturalist as the older Darwin did not think it incongruous to write his botanical treatise in verse. The former distaste which many men who were devoted to the humanities felt for science probably became most firmly rooted at the time of the great leap forward in scientific discovery in the last century, and was largely due to the natural dislike of one of the less amiable characteristics of the men of science of that time—the tendency of such men to speak as if their discoveries had torn the last veil from the face of nature. Really, of course, this conceit was in the disciples, not in the masters. As the years went on, all men of science became more and more cautious. One after another, the great scientific

generalizations that so startled our grandfathers have been found to be but faint images of unimagined truths beyond. Early dogmatism has given place to hesitancy. In its own way, the insight of a Wordsworth is as keen as the insight of a Huxley. Science is rapidly becoming reconciled with art and literature. And our older pupils should know this, and understand why.

Science is often accused of an excessive fondness for long and ugly words, but it must be remembered that the secrets of the universe are not to be revealed in monosyllables. A new principle, or a new material, or a new relation, or a new unit, must, as a rule, be given a new name; if given an old name, old associations quite foreign to the new thing would probably become attached to it, with all sorts of consequential ambiguities in its future use. The word *affinity* is an instance of the unfortunate adoption of an old term. The word suggests kinship, sympathy, attraction, ideas which confuse rather than explain the nature of chemical affinity. The word *law* is another unfortunate adoption.

There is, moreover, a complexity of thought that is properly represented by complexity of expression. When a man has devoted a life-time to the study of a difficult subject, we have no right to expect admission to his new secrets if we are unwilling even to take the trouble of learning a few unfamiliar terms. And the true man of science is never guilty of adopting such barbarisms as are sometimes met with in the commercial world. Such a term as *florigene* ("floor-hygiene") is an abomination. The term *saltrates* is as bad. "Ethyl" (the petrol mixture containing a small proportion of "anti-knock" substance purporting to be lead tetra-ethyl) is even worse.

Simplicity of Expression in Science Teaching

It ought not to be difficult for a science teacher to make himself intelligible, and to make his lessons easy of comprehension. That he will often find it necessary to introduce

new technical terms is true; that is part of his business. But these terms will almost always have a perfectly definite connotation, and their meanings will be free from ambiguity because of the absence of old associations. In short, exposition in science is ambiguous less often because of the use of technical terms than because of the incorrect and inappropriate use of ordinary words.

And yet we must distinguish between the language used in teaching science, the language commonly used by specialists in science, and the language used for lecturing to the man in the street.

If we desire to tell an audience of ordinary intelligent persons that a nebula is found to be a gas and not a collection of stars, it is easy to say so in those terms, and to give reasons, of a sort, to substantiate our statement; the audience will appreciate the fact, wonder at it, and understand it more or less. But if in the course of a lecture we tell them that "radiation involves the unimaginable transformation of the negative energy of orbital revolution into electromagnetic oscillations in an ether the fundamental properties of which we really know nothing about", or if we recite to them some specially selected passage from Lord Haldane's *Reign of Relativity*, how much do the audience understand? Is it possible to devise a form of words, within the limits of the vocabulary familiar to the audience, which will convey an intelligible meaning? Of course not. Esoteric science cannot be cast into simple language and served up to the man in the street. Its technique must always remain the secret of the expert and to the amateur be a sealed book.

And yet this technique is largely of the nature of mere tools, necessary only till clearer knowledge is obtained. We shall never teach the man in the street how to follow up his "world-lines" in "space-time", or what is meant by "warped space". Such conceptions as these are admittedly necessary for the progress of science, but it is a mistake to attempt to explain them to the uninitiated, however simple the language and however apt the illustration, if only because an uninitiated

person will never be able to work them into that part of his knowledge which consists of clear and distinct ideas. " Popular " science is best confined to the exposition of general principles and the broader lines of research. Science made intelligible is a thing worth aiming at, but science made easy is almost certain to be made unscientific.

The " popular science " lecturer should remember that he must never shirk rigorous reasoning. It is always possible that the intellect and the powers of reasoning of the man in the street may be quite as robust as his own, except that they have developed in other directions. The science of the man in the street should be as manly as that of the specialist, but it should be more general and simple in the truest sense of the word. Many technical details and many fine shades of difference will, for the man in the street, remain unknown, but that is of little consequence.

Statements at which a scientific critic would cavil need not be shunned if they convey the truth. Preference should be given even to a verbal inaccuracy if it conveys the true spirit of a thing, rather than to a correct statement which has twisted itself into an almost unintelligible form in order that the lecturer may be saved from the criticism of scientific purists.

It is exceedingly difficult to provide the right kind of fare in science for the non-specialists in the Sixth Form. Obviously such boys cannot work with the specialists; the rapidly and increasingly difficult technique being acquired by the latter makes that impossible. It has, however, to be borne in mind that there is little difference in intellectual power between the one set of boys and the other. Whatever science is provided for the non-specialists must be exacting science: there must be no doubt about the facts presented and there must be no loose reasoning. *The* difference will be largely an affair of language—a much reduced technical vocabulary. It must *not* be " popular " science. " Science for all " does not mean " Science for duffers ".

See that every technical term used and every common term used are really understood. Perhaps this is more easily

done in science than in other subjects. But nothing is rarer than the use of a word in its exact meaning. Ask an ordinary Sixth Form history specialist exactly what he means by such terms as " constitution ", " liberty ", " free trade ", " national debt ", " unearned income ", and cross-examine him on his definitions. The chances are that he will bungle badly. Even so, ask an ordinary Sixth Form science specialist to define the term " anticyclone " (coined by the late Sir Francis Galton in 1862), and the chances are at least even that he will say that the prefix *anti* signifies opposition (as in antipodes) instead of alternation (as in antiphon). Indeed, quite intelligent people are constantly using scientific terms loosely; they have never thought out the exact significance of the terms. And yet the terms are much easier to define than the terms which form the common stock of politicians, or of sociologists, or of historians. How often even well-trained Sixth Form science pupils confuse *impetus* and *momentum*; *gravity* and *inertia*; *centripetal force* and *centrifugal force*, assuming oppositions and relations that do not exist. For instance, they oppose *centripetal* and *centrifugal* forces as if they were forces in the same sense (see p. 129). *Hypothesis* and *theory* are sometimes confused, even by writers of standing.

Avoid using the term *scientist*, even though we are badly in need of a general term of some kind " to describe a cultivator of science in general ". We want a word equivalent to the French *savant* or the German *gelehrte*. " Scientist " is a hybrid. Professor Armstrong has suggested " sciencer " (cf. " geographer " and " astronomer "), but the word does not come very trippingly to the tongue. The word " scientist " is being used more and more by general writers, and doubtless its general adoption is only a question of time. *Nature* never uses it, however. Nor does any other reputable authority in the world of science.

Note-making and Note-taking

It is of the first importance that a science teacher shall be scrupulously careful always to use correct English himself; then he can be exacting over his pupils' English. The business of a science teacher, or of any other teacher, is to teach *English* as well as his special subject.

Slovenly English in any form of written work should never be accepted from pupils.

Note-taking is an art that must be *taught*. Small boys cannot be expected to make notes until they have been taught how to do it. In the very early stages, notes may be dictated, for pattern purposes; and lessons may occasionally be given on the way in which notes should be made. It will make matters simpler if the pupils have already received or are receiving précis exercises in their English lessons. Quite young children often make full and accurate records of their nature study observations; and one great advantage to be derived from nature study as a subject is that a child, having made a definite observation, then has to try to record that observation in words. Once the child has learnt to do this, half the battle is won. A succession of observations, properly classified, is the next step, and this is generally easy.

Records of laboratory work are much easier to make than records of a teacher's lecture-demonstration. In the laboratory, the boy performs a particular operation and records it. In the lecture-room, the teacher, no matter how deliberate he may be, probably says five times as much as the boy can take down, and it is almost hopeless to expect a boy below the Fifth Form to sort out the facts and put down those that matter most. In the Third and Fourth Forms, it is best for the teacher to make a pause occasionally, and so give the class an opportunity of recording their notes; a hint or two on the best way of handling the particular topic under consideration is not always inappropriate. And in these Forms a dictated note is often necessary. Formal definitions to be expressed in exact language, or difficult points of theory, may always be dictated.

In these Middle Forms, in short, the art of note-taking must be gradually *taught.* In the Fifth, boys may be thrown more and more on their own resources, and in the Sixth, entirely, though much depends on the training in the Thirds and Fourths.

The notes made in the laboratory should be final, and never written up a second time, unless this is necessary by way of a punishment for carelessness. Everything a boy does at his bench should be recorded at once in ink, as much care being taken as possible. All experimental work yielding unsatisfactory results should be honestly recorded: by that means a teacher learns exactly what progress his pupils are making. Let boys know that the cleverest investigators are constantly meeting with failures, and that these failures are really stiles on the way towards the goal of success.* Laboratory note-books are necessarily rather untidy. The teacher, the inspector, and the examiner have been through the same mill, and all recognize that some untidiness is unavoidable. But there is no excuse for unsystematic or for imperfectly recorded notes, especially in the Upper Forms. The notes of a laboratory lesson should tell the complete story of all the happenings during a lesson period.

At the demonstration table, the teacher presents the subject independently of the text-book used by the boys. His presentation is perhaps wholly different, and is in any case complementary. Whether the boys read up the subject from their text-book before or after the lesson (they will sometimes do one thing, sometimes the other, according to the subject), the demonstration will serve to throw new light upon the difficulties of the topic under treatment. The boy will see the thing from two points of view, though the experimental demonstration will naturally be the view that will strike him most. What therefore the boy records in his note-book will matter much, and to this end his training in the Thirds and Fourths is all-important.

Speaking generally, then, notes *must be original.* The systematic dictation of notes by a science teacher is a repre-

* Cf. p. 39.

hensible practice. It stamps the teacher at once as either inefficient or lazy. When a boy sees an experiment performed, or performs an experiment himself, and listens to and takes part in the discussion concerning the experiment, the thing of all things to impress the whole business on his mind is to make him express his thoughts in his own words. That which is perhaps half vague and fleeting has then to be given a definiteness, though perhaps this definiteness immediately betrays only half apprehension. The thoughts self-expressed show at once to what extent the facts taught have been assimilated.

It is a good thing for the teacher occasionally to circulate a fair copy of his own notes of a laboratory experiment or of a demonstration-table lesson, always *after* the pupils have made their own record.

When a boy is writing up an essay on a science subject, see that he never copies from his text-book. But this does not mean that from time to time he may not be told to mark down in his text-book telling sentences, or even short paragraphs, especially those concerning definitions, laws, &c., to be learnt by heart. These may be introduced in the essays, though always in inverted commas.

Do not expect much logic from small boys. But, in the Fifth and Sixth, rigorously logical notes must be invariably exacted.

Teach brevity, lucidity, simplicity.

In the writing up of laboratory notes, the use of the pronoun in the first person should be forbidden. The teacher when giving instructions naturally uses the imperative: " Take a test-tube, half fill it with water, and add a few drops of acid." The boy when writing up his notes should use the past tense of the indicative mood, but omit the pronoun as his teacher did: " Took a test-tube, half filled it with water, and added a few drops of acid." Never allow boys to adopt the irritating plan of using the past passive: " A test-tube was taken, it was half filled with water, and a few drops of acid were added." Worse still is the present passive: " A test-tube is taken, it is half filled with water, and a few drops of acid are added ":

when an experiment is described, surely the description is of something already done. Use the active voice whenever possible, and strike the object directly. Come to the point at once.

Teach paragraphing, insetting, and arrangement generally. Teach classification and tabulation. Show how notes may be best arranged to catch the eye of the reader.

Diagrams should be *diagrams*, not elaborate pictures. Never use coloured inks, except for biological diagrams. Make sketches and diagrams from the things themselves; do not copy other people's sketches and diagrams.

The correction and the marking of pupils' notes is the bugbear of the science teacher. All the books should be thoroughly overhauled twice a term, and this is easily possible if the work is properly organized. But pupils ought always to have their note-books open in the laboratory, so that recent notes can be glanced over by the teacher passing round. Never spend time over making interlinear corrections in note-books. Use symbols to indicate the *type* of mistakes, and make the boys themselves correct the mistakes.

Instruct pupils to use only the right-hand page of the note-book for making notes. The opposite side is useful for further notes, perhaps from new text-books or from library books, or of revision lessons; also for teachers' notes, for corrections, and so forth. Let everything be dated when written. Pupils should enter up *at once* on the left-hand page any criticisms made by the teacher when passing round, the entry being made opposite the note criticized. The points criticized should be indicated in the book by the teacher himself, some selected code of symbols being used. A teacher will soon know which boys tend to water down his criticisms, and this watering down should be forbidden, unless at least it refers to the teacher's own petulance of language! A little petulance is pardonable when a boy oxidizes magnesium and thereby claims to have increased the weight of the metal used by 10,000 per cent.

PART II

THE DIFFERENT SUBJECTS OF INSTRUCTION

In these chapters considerations are given to the different subjects of science usually taught, and suggestions are made as to methods of treatment. It will be observed that certain subjects do not readily lend themselves to anything of the nature of an orthodox training in laboratory procedure; they are, therefore, best dealt with in the Sixth Form, where freer methods of handling are possible.

CHAPTER XI

Mechanics

Why must Mechanics be included in any Science Course?

The question is sometimes asked if it is really *necessary* to include mechanics in a school science course. To answer this question, we may consider some complex phenomenon, say *sound*, and analyse it. By comparing the various cases in which sounds of all kinds are produced, Herschel found * that they all agreed in these points:

1. The excitement of a *motion* in the sounding body.
2. The communication of this motion to the air or other medium which is interposed between the sounding body and our ears.
3. The propagation of such motion from particle to particle of such medium in due succession.
4. Its communication, from the particles of the medium adjacent to the ear, to the ear itself.
5. Its conveyance in the ear, by a certain mechanism, to the auditory nerve.
6. The excitement of *sensation*.

Now in this analysis we notice that two principal matters must be understood before we can have a true and complete knowledge of sound:

1. The excitement and propagation of *motion*.
2. The production of *sensation*.

* See *Scientific Method*, III, xix.

These, therefore, appear to be the elementary phenomena into which the complex phenomenon of sound resolves itself.

But, again, if we consider the communication of *motion* from body to body, or from one part to another of the same body, we shall perceive that it is again resolvable into several other phenomena:

1. The original setting in motion of a material body, or any part of one.
2. The behaviour of a particle set in motion, when it meets another lying in its way, or is otherwise impeded or influenced by its connexion with surrounding particles.
3. The behaviour of the particles so impeding or influencing it in such circumstances.

   The last two suggest another phenomenon which it is necessary also to consider, viz:
4. The phenomenon of the connexion of the parts of material bodies in masses, by which they form aggregates, and are enabled to influence each other's motions.

Thus we see that an analysis of the phenomenon of sound leads to the inquiry—

1. Into two *causes*, viz.,

   (*a*) The cause of *motion*,
   (*b*) The cause of *sensation*,

   these being phenomena which we seem to be unable to analyse further, and we therefore set them down as simple, elementary, and referable, for anything we can see to the contrary, to the immediate action of their causes.

2. Into several questions relating to the connexion between the motion of material bodies and its cause; for example,

   (*a*) *What will happen* when a moving body is surrounded on all sides by others not in motion?

(*b*) *What will happen* when a body not in motion is advanced upon by a moving one?

It is evident that the answers to such questions as these can be no others than *laws of motion*.

Lastly, we are led, by pursuing the analysis and considering the phenomenon of the aggregation of the parts of material bodies, and the way in which they influence each other, to two other general phenomena, namely, the *cohesion* and *elasticity* of matter; and these, again, we may regard as simple elementary phenomena referable to the immediate action of their causes. Almost any physical phenomenon is, ultimately, similarly reducible. Mechanics forms the foundation of every branch of science, including even biology. A knowledge of its main principles is therefore essential to a right understanding of whatever science is taught.

The Teacher of Mechanics

Until the present century, mechanics was sometimes called " applied mathematics " or " mixed mathematics ", and even university degrees in mathematics, with mechanics as a chief subject, have been given to students who never handled a machine or a piece of mechanism in their lives. Formulæ were evolved from the consideration of a few geometrical diagrams having the very slenderest relations to practical life; and the rest of the work consisted in applying these formulæ to the working out of all sorts of tricky problems, most of them having little or no relation to realities. " Mechanics ", forsooth!

Now all this is changed, though several text-books of the old type survive. Mechanics is now regarded as a branch of physics rather than of mathematics, and a subject to be established on an experimental basis.

The most successful teachers of mechanics whom I have known are those who have had a serious training in a mechanical laboratory; who know something of engineering, and are familiar with modern mechanism; who are competent mathe-

maticians; and who have mastered Mach's *Mechanics*, especially Chapters I and II.* Mach's book is universally recognized as *the* book for all teachers of mechanics. It deals with the development of the fundamental principles of the subject, traces them to their origin, and deals with them historically and critically. The treatment is masterly. The book might with advantage be supplemented by Stallo's *Concepts of Modern Physics* (now rather out of date from some points of view), Karl Pearson's *Grammar of Science*, and Clifford's *Common Sense of the Exact Sciences* and *Lectures and Essays*.

It is of great advantage to a teacher of mechanics to be familiar with the subject historically. The main ideas of the subject have almost always emerged from the investigation of very simple mechanical processes, and an analysis of the history of the discussions concerning these is the most effective method of getting down to bedrock.

Who were the great investigators? The scientific treatment of statics was initiated by Archimedes (287–212 B.C.), who is truly the father of that branch of mechanics. The work he did was amazing, but there was then a halt for 1700 or 1800 years, when we come to Leonardo, Galileo, Stevinus, and Huygens; to Torricelli and Pascal; and to Guericke and Boyle. For dynamics, we go first to its founder Galileo (falling bodies, and motion of projectiles), then to Huygens (the pendulum, centripetal acceleration, magnitude of acceleration due to gravity), and then to Newton (gravitation, laws of motion). The great principles established by Newton have been universally accepted almost down to the present time, and, so far as ordinary school work is concerned, will continue to be used —at least during the present generation.

A boy is always impressed by Newton's argument that since the attraction of gravity is observed to prevail not only on the surface of the earth but also on high mountains and in deep mines, the question naturally arises whether it must not also operate at greater heights and depths, whether even the moon

* Hertz also wrote a *Mechanics* of the same masterly kind, but there is no English translation, so far as I know.

must not be subject to it. And the boy is still more impressed by the story of the success of Newton's subsequent investigation.

Newton's four rules for the conduct of scientific investigation (*regulae philosophandi*) are the key to the whole of his work, and should be borne in mind by his readers.

The First Stage in the Teaching of Mechanics

How do successful teachers begin mechanics with boys of about 12 or 13? They usually begin by drawing upon the boys' stock of knowledge of mechanism.* Most boys know something of mechanism, some will have had enough curiosity to discover a great deal, and a few will probably have had experience of taking to pieces machines of some sort and of putting them together again. This stock of knowledge may be sorted out, and the topics classified and made the subjects of a series of lessons. By means of an informal lesson on some piece of mechanism, an important principle may often be worked out, at least in a rough way.

I have known a teacher give his first lesson on mechanics in the school workshop, utilizing the power-driven lathe and the drilling machine; another first lesson in the school playground, an ordinary bicycle being taken to pieces. I have seen a model steam-engine used for the same purpose, and I have known beginners taken to a local farm to watch agricultural machinery at work. In all these instances the boys learnt that their new subject seemed to have a very close relation with practical life. They were not made to look upon it as another branch of mathematics, and a rather difficult branch at that.

Let the early lessons be lessons to establish very simple principles. Never mind refinements and very accurate measurements. Do not bother about small details, and avoid all complications. Let the boy get the *idea*, and get it clearly. Very simple arithmetical verifications are quite enough at this stage. The boy's curiosity is at first qualitative; let that be whetted first, and then turned into a quantitative direction gradually.

* See Chapter VIII, *Lower Form Science*.

Encourage the boy to find out things for himself, and do not tell him more than is really necessary. Encourage him to ask questions, but as often as possible answer these by asking other questions which will put him on a new line of inquiry. Let him accumulate knowledge of machines and machine processes. Give him some scales and weights, and a steelyard, and tell him just enough to enable him to discover the principle of moments, but do not talk at first about either " principle " or " moments ". It is good enough if at this stage he suggests that

$$\text{long arm} \times \text{little weight} = \text{short arm} \times \text{big weight.}$$

He has the *idea*, and the idea is expressed in such a form that it *sticks*. Give him a model wheel and axle, give him a hint that it is really the lever and the lever-law over again, and make him show this clearly. Give him some pulleys and let him discover, with the help of one or two leading questions, how a small weight may be made to pull up a big weight, and let him work out the same law once more, but now in the form that what is gained in power is lost in speed. Give him a triangular block and an endless chain, let him repeat Stevinus' experiment, and so discover the secret of the inclined plane. Let him use a jack to raise your motor-car (and incidentally learn something about " work "); now tell him something about the pitch of the screw, something about Whitworth's device for measuring very small increases in length, something about the manufacture of a Rowlands grating. Encourage him to give explanations of mechanical happenings in everyday life, and use his suggestions as pegs on which to hang something new.

A term of this kind of work pays. The boy is accumulating knowledge of the right sort, and when the subject is taken up more formally and with a more logical sequence, rapid progress may be made. Once he has been taught to read elementary mechanism, it is easy enough to teach him its grammar. Surely this is the right sequence. Mechanism must come

before mechanics. The mathematics of the subject is a superstructure, to be built upon a foundation of clear ideas.

Of course, if the preliminary work of the preparatory school or department has been properly done, the way is paved for an earlier treatment of a more formal kind.

The Second Stage

The second stage will consist of work of a more systematic character, but still work essentially practical, though arranged on a logical string. Ideas will now be classified, and mathematical relations gradually introduced. But the physical thing and the physical action must still remain in the front of the boy's mind. The mathematics will take care of itself.

Let the teaching be inductive as far as possible. Obtain all necessary facts from experiments, and do not use experiments merely for verifying a principle enunciated dogmatically.

The basic principles to be taught are really very few, and a boy who knows these thoroughly well can work most ordinary problems on them. Mechanics is, after all, largely a matter of common sense. The laws of equilibrium, together with the ratio of stress to strain, covers almost the whole range of statical problems, including those of hydrostatics; while Newton's Laws of Motion cover practically everything else. But of course these are basic principles. If they are known, *known*, derived principles are learnt easily enough; if they are only vaguely known, derived principles are never really mastered.

Statics or dynamics * first? Teachers do not agree. There is much to be said for beginning with dynamics, first using the ballistic balance for studying colliding bodies, and the momentum lost by one and gained by another; it is then an easy step to pass on to the idea of force. But a boy who is led to think of a force as something analogous to muscular effort will always be in trouble, and in any case he is likely to form a very vague idea of acceleration. And, after all, uniform acceleration is anything but common in practical life: we nearly always refer

* The terms kinetics and kinematics are falling into disuse.

either to falling bodies or to a train moving out from a station. It is this difficulty that makes many teachers take up statics first. Although, at the outset, a boy's working idea of force is necessarily crude, a spring balance, for simple quantitative experiments, helps to put the boy on the right track, and there is much to be said for allowing him to assume, to begin with, that *weight* is the fundamental thing to be associated with force. At an early stage he may verify, to his own satisfaction, the principles of the parallelogram and triangle of forces, but he must be warned that he has not yet "proved" these principles and cannot yet do so. But since the parallelogram of forces is such a useful working principle, it would be foolish not to allow the boy to use it before he can prove it formally. At this stage formal proofs are difficult, and it is simply dishonest to encourage a boy to reproduce a page of bookwork giving a proof of something quite beyond his comprehension, though this was common enough thirty or forty years ago.

Do not employ graphic statics at too early a stage, or the real point at issue may be obscured.

Now as to dynamics. What is the best approach? We have already referred to the ballistic balance. Should Atwood's machine be used? It may be used, perhaps, for illustrating the laws of motion, but not as a practical method of finding g.

Atwood's machine has been superseded by Mr. Fletcher's trolley,* by means of which practically the whole of the principles of dynamics may be satisfactorily demonstrated. It lends itself to many experiments, all of which provide a space-time curve ready made, and, from that, speed-time and acceleration-time curves may be plotted. In a paper read at the York meeting of the British Association, Mr. C. E. Ashford gave details of a large number of trolley experiments as performed at Dartmouth, a school where the teaching of mechanics is well known to be of a high order. Reference has already been made to Mr. Fletcher's own article in the *School World* for

* The friction of the trolley may be eliminated either by tilting the plane to the necessary angle, or by attaching a weight that will just maintain uniform motion. The friction of the pulley over which the thread passes cannot be compensated, and it is therefore necessary to use a good pulley.

May, 1904. In it he shows how boys may be given sound ideas of the physical meaning of the terms, moment of inertia, angular momentum, moment of momentum, and therefore of moment of rate of change of momentum and moment of force. Useful teaching hints may also be found in Mr. S. H. Wells's *Practical Mechanics* and Mr. W. D. Eggar's *Mechanics*.

Once the foundations of mechanics have been well and truly laid the superstructure may be erected according to traditional methods. To leave the subject just as developed in the laboratory would be to leave it unfinished. But the superstructure may now be built properly. When necessary formulæ have been evolved from experiment, the physical things behind the formulæ have to the boy a reality of meaning which the older "methods of applied mathematics" teaching could not possibly give him.

If principles are not understood, proofs have no meaning.

Throughout the whole of a mechanics course, every opportunity should be taken to excite the boys' interest in new mechanical inventions. It helps the more academic work enormously, and makes the boys feel that the subject is really worth taking trouble over. Examples occur on every side—variable speed gears, transmission gears, taximeters, boat-lowering gear, automatic railway signalling, automatic telephones, the self starter in a motor-car, the kick-starter in a motor-cycle, and so on. Some mechanical devices depend, in their turn, on electricity, and their place of introduction into a teaching course would be determined accordingly. Complex mechanisms like the air-plane, the submarine, the paravane, should not be wholly forgotten. Boys can read up such things for themselves, and perhaps prepare and read papers on them to the school science society.

Hydrostatics

The mechanics of fluids is an exceedingly difficult subject to teach effectively. Even a Sixth Form boy is sometimes held up by questions on the barometer or on Dulong and Petit's

equilibrating columns. The work of Archimedes and Pascal for liquids and of Boyle for gases cannot be too well done. Above all, the U-tube must receive careful attention, and especially the surface level above which pressures are compared. Do not buy Hare's apparatus from an instrument maker's. The standard pattern is always made with two straight tubes, of the same bore, fixed vertically. Let the boys make a variety of forms of this apparatus for themselves, and work out the vertical height law from data as varied as possible. Approach the whole subject of hydrostatics from the point of view of familiar phenomena, e.g. measure the water pressure from a tap in the basement and again from a tap in the top story of the school, and see if there is any sort of relation between the difference of these pressures and the height of the school. *Do not try to establish a principle formally until the phenomenon under investigation is clearly understood as a physical happening.* Let boys know really *what* they are going to measure before they begin to measure.

Some Snags

FORCE.—Do not try to define the term *force*. What is the use of saying, " Force is ' that ' which produces motion "? How are we then to define the term " that "? Suppose we say, " Force is the (vector) rate of change of momentum." What boy will understand, *really* understand? A boy has some sort of working idea of force, right from the first; he knows that a force is acting when a thing is being pushed or pulled about; later, he associates force with weight; still later, a clearer idea begins to dawn. But it is foolish to make the boy *define* the term. And if a ready-made definition is given him, it will almost certainly be open to criticism.

When we say that force is the product of mass and acceleration, we do not *define* force. We may say that two forces are equal when they give the same acceleration to the same mass; or, we may say they are equal if, acting in opposite directions, they are in equilibrium. But this is not a definition of force.

A force applied to a body cannot be uncoupled and applied to another body, as an engine is uncoupled from a train and coupled to another. How then is it possible to say what acceleration a force applied to a first body would give to a second body if applied to it? The rule that the force acting on a body is equal to the product of its mass and acceleration depends on the possibility of measuring three magnitudes, the *force*, the *mass*, and the *acceleration*. But mass is not capable of measurement independently of the notion of the equality of two forces. We do not define the smell of sulphuretted hydrogen as the product of the separate smells of sulphur and hydrogen. The analogy is admittedly entirely irrelevant, but it is scarcely more illogical. Poincaré rightly points out that when we say that force is the cause of motion, we are talking metaphysics. We are certainly not *defining* force. No boy can be expected to frame a satisfactory definition, and he should not be asked to do so. If any teacher is able to frame the definition, by all means let him pass it on to his class. But *is* he able to do it?

Never accept from a boy such a statement as

$$\frac{\text{force acting}}{\text{acceleration produced}} = \frac{\text{weight}}{g}.$$

A "mixed ratio" boy should be handed over to the chief mathematical master to be put in a special pillory.

Centripetal and Centrifugal.—To teach the meaning of "centripetal force", illustrations must be used carefully: a ball whirled round at the end of a string will do to begin with; then call in illustrations from astronomy. The beginner is always puzzled; he says: "If there is a force, there must be acceleration, but in this case the velocity is constant and there is therefore *no* acceleration." A force which continually acts but seems to do no work save that of causing continual change of direction does not seem to the boy to be on all fours with the forces he is already familiar with. "There may be a change of direction, but there is no change of speed; how then can

there be acceleration?" The boy has got into his mind a too limited connotation of the term acceleration, and the teacher must clear up his difficulty. It is best to avoid altogether the term "centrifugal force". Boys are apt to think of it as a force acting directly outward, instead of as a *tangential* force. It is quite true that we may correctly regard the two forces (centripetal and centrifugal) as constituting the stresses in the string, but the term centrifugal force is nevertheless best not used.

ACCELERATION.—The generally accepted use of this term must remain the use for school purposes, but Sixth Form boys should be warned that the term is by no means so simple as it is often thought to be. As Professor Hobson points out, "the acceleration of a body" has no logical meaning unless either the body be of negligible dimensions or the acceleration be taken to mean the acceleration of some one particular point in the body; for, in general, a body can move not only translationally but also rotationally, and thus different parts of the body may have different accelerations. In order that Newton's laws may have a precise meaning, it must be assumed either that the bodies referred to in them are considered as masses concentrated at points, or as bodies which, though of definite size, are, at their centroids, equivalent to such concentrated masses, the forces between any pair of such bodies being along the straight line joining their centroids.—This is of little or no consequence in ordinary school practice, but Sixth Form boys should be aware of it.

CONSERVATION OF ENERGY, OF MATTER, AND OF MASS.—Here again a warning is necessary in the Sixth Form, though the older notions will continue to be used in the Fifth.

The term *energy* is of comparatively recent introduction and represents the work that may be done by forces acting on matter. It may be observed and measured in a multitude of forms. It may take the form of sound, light, heat, electric charge, electric current, raised weights, bent springs, moving and spinning bodies, and radiation generally. But it has been

found that radiation strangely simulates some of the properties of matter. It exerts a minute pressure on bodies receiving it, exactly as if it possessed momentum, and it therefore looks as if radiation is itself a form of matter, even if only a temporary form. The electrical theory of matter emphasizes the shadowy nature of the distinction between matter and energy. It looks, indeed, as if matter were merely a form of energy. Thus a teacher must be on his guard against giving too much emphasis to the doctrines of the conservation of matter and energy.

When we talk about the conservation of matter, we certainly do not mean that such physical properties as extension, colour, hardness, conductibility of heat and electricity, &c., persist unchanged, for they are subject to very large changes in what we regard as one and the same material system. What, then, is a boy to understand by the statement that matter can neither be created nor destroyed? If we assert that what persists unchanged is a sub-stratum, substance itself, not identifiable with any of the physical properties but regarded as their bearer, we make verification impossible, and our assertion belongs to the realm of metaphysics, not of science. What is a boy to make of it?

We cannot infer that conservation of matter means conservation of weight, for weight varies with the place where it is measured. But if, for different localities, we divide the weight by acceleration due to gravity, we obtain a measure of the mass of the body, and then the conservation of matter is reduced to the conservation of mass. And conservation of mass seems to imply that mass, as a measurable quantity, is unchanged in amount throughout all the chemical and thermal changes that may take place in an isolated material system.

But our increasing knowledge of electrons is driving us to the conclusion that mass does not occupy the simple position that hitherto has been assigned to it in the mechanical theory referred to. In fact, we may no longer assume that mechanical masses of bodies are constant. Dynamical mass may no longer be regarded as fundamental and irreducible.—The Sixth Form boy should know this, but he may be told frankly that, at least

for the present, all problems in physics must be solved in the old way, our knowledge of the intimacy of relationship between matter and energy being still very fragmentary.

Units

Although written half a century ago, Dr. W. Garnett's *Elementary Dynamics* deals with the question of units in a way that has always been regarded as exceptionally clear and complete, and every teacher of mechanics should read it. Professor Hicks's book on the same subject is also excellent. And generations of science teachers have been familiar with Everett's C.G.S. system of units. In short, the subject of units has been treated so exhaustively, so clearly, and so often, that both from the point of view of science and from that of teaching there is really no more to be said. Yet teachers do not agree as to the best methods of procedure or, in fact, about the units to be used.

About certain things, however, all agree. One is that a boy must clearly understand what is meant by fundamental units and by derived units; another, that he must clearly understand that the measure of a quantity varies inversely as the magnitude of the unit; a third, that it is desirable he should be able to write down at once the dimensions of a derived unit, even though in the actual measuring of such units he does not have recourse to the fundamental units (for instance, in measuring a velocity he might take as the unit of velocity the velocity of sound). But whether preference should be given to *weight* or *mass*, or to the use of *pound* or *poundal*, teachers simply will not agree.

There is much to be said for adopting, in the first place, a unit appropriate to the business in hand, e.g. the *ton* for coal, the *pound* for sugar, the *ounce* for pepper, the *grain* for strychnine. There are circumstances in which we might speak of the ton-mile-hour unit much more appropriately than the centimetre-gramme-second unit.

A beginner often confuses mass and weight, and is it surprising? Try to help him to obtain a precise notion of weight

as a downwardly directed force; help to clarify his notion of mass by reference to bulks of material with which he is familiar, the bulk of a pound of butter, of a two-pound loaf of bread, the amount of stuff quite apart from its weight. Tell him to imagine a person living in the moon and buying a pound of butter there: how would the bulk of the butter compare with the bulk of a pound sold on the earth. He will soon get the right idea of the distinction between mass and weight, even if he cannot express himself satisfactorily in words. And the distinction is all important.

Make the boy understand that the mechanical engineer uses the unit of *weight*. The mechanical engineer regards weight—the pull of the earth—as the fundamental quantity, and looks upon mass as a subsidiary thing. But the electrical engineer and the physicist regard *mass* as the fundamental unit, and look upon gravitation as something quite unimportant.—The boy must be taught never to mix up the two ideas. Wherever in a problem based on gravitation m comes in, m must be replaced by W/g. But if mass is to be the fundamental unit, wherever in the problem W comes in, W must be replaced by mg. Numerically the problem must have W all the way through, or m all the way through, the equalizing equation being $W = mg$. In earlier experiments in mechanics real weights are naturally used, and the beginner becomes familiar with W. From the first he should use this symbol in his calculations, and by the time he reaches the subject of gravity, and learns that W (or F) $= mg$, the W will be an old friend. It is a mistake to allow a boy to use m in his equations, until he has covered a good deal of elementary ground.

Boys' answers to questions in mechanics are often wrong because of confusion of units. This is shown at once by the answer being a recognizable multiple or quotient of the correct answer, and the boy's particular blunder thus stands revealed. Momentum is confused with work done; g is called a force; and so on.

It pays to teach units very thoroughly, whatever a teacher's pet scheme of units may happen to be.

CHAPTER XII

Physics

The Normal Course: General Considerations

In physics, even more than in chemistry, the signs of the times are that teachers are no longer wedded to the traditional method of beginning the subject by rigorously establishing first principles, and finishing it by making casual references to applications in everyday life and by providing the boys with little arithmetical problems in preparation for the examination day. Teachers no longer fear to offend the rules of logic, and they no longer shrink from allowing boys to contribute knowledge already acquired from other sources.

In any branch of physics, there is much to be said for developing the subject from some selected topic about which the pupils already have a certain amount of general knowledge. Suppose, for instance, that a course on *heat* is to include, as its principal feature, the study of internal- and external-combustion engines. Beginners might, at the outset, be given an insight into the working parts of an ordinary steam-engine (stationary or locomotive), and of a motor-cycle or motor-car; as much, say, as a repairing workman or a competent driver could give them. The facts gleaned and suggested during these (say) two first lessons would be sorted out and amplified in such a way that they could be grouped under the usual headings: expansion, colorimetry, change of state, and so forth; and in this fashion a course of work could be drawn up on almost orthodox lines. But the boys would feel that the course was really the outcome of their own suggestions made concerning things in which they would be interested all their lives, and not a course thrust upon them for examination purposes. Revision towards the end of the course would include another examination of the engines, but this time the examina-

tion would be a scientific examination, based on much fuller knowledge. Boys are always impressed with the use, made by inventors, of ordinary scientific principles.

Alternatively, the subject might be approached in a different way, the American " topic " method supplying the key idea. The class of beginners would be asked to give instances of apparatus or of machines or of phenomena in which heat and cold are concerned: a kitchen-range, a gas-cooker, a kettle, a bunsen burner, a thermos flask, a foot-warmer, a thermometer, a bursting boiler, the putting of a tyre on a wheel, and a score of other things. As before, there would be a sorting out and grouping of the suggestions; main principles would be established one by one in the usual way, a particular phenomenon suggested by the boys being made a thing to work *from*, and to remain the centre of interest.

Suppose a course of *light* is to lead up to a knowledge of optical instruments. The boys might, to begin with, be supplied with a few instruments, say a common magnifying glass, a kaleidoscope, an old telescope, perhaps even an old microscope with a coarse objective, and told to gather what knowledge they could, consulting books if they liked, but warned, of course, about the careful handling of the instruments. They will glean all sorts of odds and ends of information, some correct and useful, some crude and worthless, and over some things they will be greatly puzzled. It is easy to convince them now that they have much to learn, and, if thought necessary, an ordinary traditional course of work may be imposed on them, to be readily accepted because of a recognition and understanding of its value. In teaching light, it is particularly necessary to try to make the pupils understand the actual physical nature of optical phenomena. Do not be in a hurry to reduce the phenomena to mere geometry. The geometry must come, of course, but it must take a second and not a first place.

Suppose a course of *sound* is to lead up to a knowledge of musical instruments. Begin with the examination of, say, a piano, and compare with a violin. The boys will learn much if they are encouraged to talk things over amongst themselves,

and the monochord will soon become child's play to them. Wind instruments are more difficult. Begin, perhaps, with a tin whistle, and then with some kind of free-reed instrument like the harmonium. The cornet and kindred instruments are too difficult until a later stage. And the grand organ can be treated only as a complicated piece of mechanism with secrets too difficult for any but advanced pupils to unravel, though the keys (with manuals and pedals), the stops, the sound boards, the wind-chest and valves, and the pipes, all lend themselves to a preliminary treatment within a fairly elementary course. But, after all, the proper understanding of wind instruments will usually be made to depend on a close study of the laboratory pattern organ-pipe. Until this is done, little headway can be made by induction from facts produced by simple experiments on complete wind instruments. It must be admitted that sound is a difficult subject to teach, though much of the matter of the ordinary text-books is unsuitable and unnecessary in a school course and might, without much loss, be consigned to the academic dust-bin. It is doubtful wisdom to take up the subject in the Middle Forms, though Sixth Form boys ought to have clear ideas of the principle underlying wave-motion, interference, resonance, harmonics, and the measurement of the velocity of sound, if nothing more.

Suppose a course of *electricity* is to lead up to a knowledge of electric lighting and electric traction, as undoubtedly it should. In such circumstances, is there any need to teach static electricity at all? Probably not, though some teachers say they can never give their pupils clear notions of potential unless they approach the subject through electrostatics.

After a few preliminary lessons on the production and properties of an electric current, a boy may be given a first insight into the school or house electric lighting installation. He will quickly understand the supply cable and dividing box, the meter, the main fuse, the main switch, and get some preliminary notion of the distribution board and the wires to the lamps. The transformer (if any) should be considered at a later stage, but enough will have been done to get the boy

thoroughly interested in the subject as having great practical value.

Most town boys will be able to contribute something to the common stock of knowledge concerning special systems of electric lighting—industrial lighting, shop-window lighting, street lighting, domestic lighting, the lighting of public buildings, theatre lighting, train lighting, electric signs, motor-car headlights and anti-glare devices—all applications of a single main principle but with engineering and mechanical differences that make a strong appeal to a boy. Call for such contributions of knowledge, sort out the facts, reduce them to the very few and easily understood underlying principles, and make the boys realize how extraordinarily useful a knowledge of electricity is.

There is this in common with electric lighting and traction, that both have the same parentage, viz. the dynamo and the motor; all else is accessory. Hence the teaching must be concentrated on these two things: the development of electrical energy and its transformation into other forms of energy. The course of instruction can therefore be planned out with that end in view. Electro-dynamics, electro-magnetics, and induction of currents, will be of primary importance; the careful consideration of electromotive force and resistance will therefore find an early place in the sequence of topics forming the syllabus of work; and the boys should make an early and close acquaintance with the various everyday working instruments of which the galvanometer is the type.

In short, before drafting a working syllabus in any branch of physics, decide upon the *end in view*. The ordinary text-book sometimes tries to provide the needs of many ends at the same time, and the boy completes his course without clear-cut notions of any part of the subject as a unity.

Present-day Developments in Electrical Courses

In any present-day course in electricity, a boy must become familiar with all the common electrical units—the *ohm*, *volt*,

ampere, *joule*, *watt*, and *kilowatt*, PRACTICALLY. He must get to know them as he knows the foot, the metre, the pound, the cubic centimetre, &c. He should become quite familiar with the voltage of the ordinary supply cable, and with the current consumed by the ordinary electric lamp. Such examples of transformations as the following should become mere child's play to him.

1. If a lamp which takes $\frac{2}{3}$ ampere is placed upon a current having a pressure difference of 100 volts, the lamp would be taking $100 \times \frac{2}{3}$ (= 66 +) watts, and this is the measure of the rate at which energy is being supplied to the lamp, and converted by it into light and heat.

2. If a 16-c.p. lamp is traversed by a current of $\frac{2}{3}$ ampere, working at 100 volts, the resistance of the lamp filament $= \dfrac{100 \text{ (volts)}}{\frac{2}{3} \text{ (ampere)}} = 150$ ohms.

3. If a man raises 55 lb. 1 foot every second, he does $\frac{1}{10}$ h.p.

4. Twenty 100-volt lamps each taking $\frac{1}{2}$ ampere would be using $(\frac{1}{2} \times 100 \times 20)$ watts = 1000 watts = 1 kilowatt = $1\frac{1}{3}$ h.p.

5. If a man raises 1 lb. 9 in. high, he does 1 joule of work.

6. If he does 1 joule of work every second, his *rate* of doing work = 1 watt = $\frac{1}{746}$ h.p.

If these transformations are in any sense arithmetical puzzles to the boy, it is evident that he is not familiar enough with the units and their relations *practically*. *Practical* familiarity is essential, and the school electric supply current is probably the best means of giving concrete notions. Boys can easily be made to see why the current supplied to every house in the town is maintained uniformly at the same pressure (voltage), although the current consumed varies with the house. (The water supply and pressure give a useful analogy.) An interesting problem for boys to try to solve: why does a very slight increase in pressure cause a great increase in the amount of light?

Pressure and current are constantly confused by boys.

Visits to generating stations are of great value, especially

if the sympathy of the engineer in charge can be enlisted. The great majority of school experiments in electricity are necessarily on a toy-like scale, and the boys ought to see the real thing.

Electric traction forms a fitting sequel to lighting considerations. New points: the continuous connexion between the motor on the vehicle and the stationary dynamo, viz. by means of either a third rail or an overhead conductor (the old stud system still survives in Lincoln); the reduction of the 5000 volts from the central station to 500 volts for distribution, and why; contrast the rapid acceleration of an electric train with the gradual acceleration of a steam-engine (the motor gives its maximum torque at starting); and so on.

Telegraphy and telephony should be included in any school course. But although telegraphing by wire and cable lends itself to comparatively elementary demonstration and explanation, wireless telegraphy is a subject for older rather than for younger boys, except on the practical side.

A similar remark applies to telephony. As a practical instrument, the telephone is easily understood, and a school installation may well be undertaken by the boys. But the theory of the telephone is rather difficult. The conversion of the original sound vibrations into undulating currents of electricity, and the subsequent reproduction of the vibrations, can be dealt with effectively only as the sequel to a sound general knowledge of elementary physics. The precautions to be taken against the inductive effects between neighbouring wires is only one of several sources of puzzlement to boys.

By all means encourage boys to interest themselves in "wireless". They learn much from rigging up a "set" of their own. But the theoretical considerations of the subject cannot be taken until fairly late in the school course. And any attempt to teach the theory of wireless *before* some knowledge on the practical side has been acquired is not likely to prove successful.

Before the close of any school course in electricity, provision should be made for a review of the whole subject historically.

A new and interesting light is thrown upon the subject when boys see how the original crude notions of electricity and its production have been gradually transformed by successive investigators. Such names as Gilbert, Franklin, Œpinus, Cavendish, Coulomb, Poisson, Galvani, Volta, Woolaston, Davy, Oersted, Ampère, Ohm, Faraday, Maxwell, and Kelvin appear on the pages of almost every text-book, but few boys realize what great steps forward these men made in electrical science. To appreciate what each worker did, the boys must understand the limited state of knowledge at the time he lived. Unfortunately, school life is not long enough to do much in this direction, but boys should be encouraged to read such books as *Faraday as a Discoverer* and learn something of the man, of his methods, and of the world of science into which he was born.

The Necessity for a Greater Width in a Physics Course

The content of a school physics course is often unduly limited. Important parts of a subject are sacrificed to academic considerations of no practical value. The mathematics of physics occupies much too large a place, and lesson after lesson is devoted to mere algebra.

"General physics" needs far more attention, as was pointed out in the Prime Minister's Science Committee's Report. And this does not refer merely to the group of subjects sometimes summed up under the term "properties of matter" (capillarity, surface-tension, viscosity, &c.), but to the working of such things as airships, airplanes, submarines, turbines, where the whole thing is a complex (so to speak) of associated mechanical and physical principles, and will well repay careful analytical treatment.

Consider such a common thing as a gramophone. As a practical instrument it is easy enough to understand, but its adequate consideration, theoretically, demands a sound elementary knowledge of physics. An instructive visit may be paid

to a gramophone factory, in order that boys may observe the successive processes in the manufacture of a record—the moulding and shaving of blanks, the taking of a record, the duplication of a record, the production and duplication of matrices, and the like: such a wonderfully simple series of manufacturing artifices is to the boys a revelation. The boys are *interested*, and are now keen to understand the reproducing machine, the gramophone itself. This machine readily reveals all its secrets save one, viz. that of the so-called sound-box and diaphragm, and at this stage the physics teacher has to step in. But of course the boys will not be able to understand the actual recording and reproduction of sound unless their previous physics course has included lessons on wave analysis.

Of all subjects in physics, *wave-motion* probably stands first. In importance, it ranks perhaps even before energy. It is at the bottom of everything else—sound, heat, light, electricity, magnetism. It *must* be taught and taught thoroughly, otherwise nothing will be understood properly. Even Sixth Form boys sometimes confuse wave-motion with the to-and-fro or up-and-down motion of the medium. And they do not always understand clearly the connexion between wave-length and frequency, or the way in which the velocity of a wave depends on the elasticity and density of the medium. Begin with visible water-waves. Then pass on to invisible air-waves; tuning-fork records may be made, and wave-length and frequency demonstrated. Let the boys see and understand that, e.g., the middle A on the piano (the orchestra tuning-note) has a frequency of 217, and since the velocity of the sound-wave is 1132 feet per second, the wave-length in this case must be 5 feet 2 inches. Show clearly how we know that there *are* air waves. Then we come to æther waves. Give a short account of Maxwell's forecast in 1864 and Hertz's first laboratory success in 1887; then of the work of Lodge, Marconi, and Fleming. Consider first an æther wave of, say, 300 metres in length; since the velocity of light is 300,000,000 metres a second, the frequency of the wave must be 1,000,000. Thus if the wave-length of a wireless station is 365 metres, receivers must be

tuned to a frequency of 822,137. But the water-wave and the air-wave must come first; to a boy they seem to have a greater reality than an æther wave. One important point for a boy to understand about waves is that *velocity* is nearly always measurable; and that if either *length* or *frequency* is then measurable, the other can be calculated from the relation $v = nl$.

It is well to emphasize the importance of a knowledge of waves and wave-motion by giving some account of interesting applications. One such application is Constantinesco's transmission of power through water by means of wave impulses. And boys are always interested in Constantinesco's synchronizing gear by means of which a Vickers machine gun could fire over 1000 bullets a minute through the rapidly revolving propeller blades of an airplane.

We have already referred to the importance of *energy* as a main subject of physics. In schools it does not receive anything like the amount of attention it deserves, and the whole of physics might very well be taught as just different aspects of energy. It would not be inappropriate to define physics as the science of energy transformations.

Can a Sixth Form boy give an exact explanation of the action of the various toys he used when a child, or of the familiar phenomena and things of everyday life—a spinning-top, a Cartesian diver, a fountain-pen, the tears on a wine-glass, the geometrical form of snow-crystals, a bubble of froth, the special qualities of a cricket ball, and a hundred others? If not, can it be said that his knowledge of physics is satisfactory?

Practical Physics

There are now so many excellent books on practical physics published that the difficulty is to make the best choice. Even some of the older ones should still find a place on every teacher's shelves, e.g. Glazebrook and Shaw's and Stewart and Gee's. The older books often give invaluable hints on manipulation, hints that are apt to be crowded out from a newer book. But some of the older books must be used with circumspection.

They contain descriptions of experiments that are no longer worth including in a school course; on the other hand many experiments which now ought to be included naturally find no place in such books. The books were written at a time when, e.g., current was not available for laboratory experiments, and such experiments as were suggested were sometimes very remote from practical life, and not infrequently they failed to demonstrate or to verify adequately the principle for which they were specially devised.

An important point sometimes overlooked in practical work is the necessity for comparing different types of instruments all having a common ancestry. Consider, for instance, the number of electrical instruments consisting, essentially, of a coil and a needle? Why the differences in pattern, why the differences in the needles and in the coils? The *differences* are the key, as differences always are in methods of scientific investigation. It is not enough to *tell* a boy about the differences between different types of galvanometers, ammeters, voltmeters, &c. He must examine the coils and examine the needles, and see the differences for himself.

More Snags

THE THEORY OF HEARING.—Is it of any use to spend time in trying to make Sixth Form boys understand Helmholtz's resonance theory of hearing? Probably not, since the theory can no longer be upheld. An outline of the theory might be given, and then reasons for its rejection. It is to be regretted that many physiology text-books continue to compare the fibres of the basilar membrane with piano strings. A continuous, very small, spread-out membrane, varying in width from the base upwards in the proportion of about 1 to 10, is supposed to contain a series of end organs which must number at least 2000, each being delicately attuned to vibrate in sympathy with one periodic vibration only; and this marvellous collection of resonators must be fully developed at birth! Helmholtz first thought that the external pillars of the organs of Corti

were the resonators, but when it was shown that these do not exist in birds, which have particularly acute hearing, he abandoned the external pillars in favour of the fibres of the basilar membrane. Nearly every other structure of the cochlea has at one time or another been credited with the function of a resonator.

It is a matter of observation that the broad fibres of the basilar membrane are all imbedded in a membrane and are forced to move together with no chance of vibrating singly; also that the membrane is in liquid, with no power to move against it. How can such delicate fibres with no chance of being tuned under tension, be compared to piano strings? What is the use of illustrating Helmholtz's theory by experimenting with hard materials like brass resonators or steel wires, and using as the exciting vibrations the vibrations of tuning-forks maintained at constant pitch?

The basilar membrane and its fibres are probably non-elastic tissues, and are therefore non-vibrating bodies which have no resonance periods of their own. Moreover the membrane being in a liquid must follow the movements of that liquid exactly.

It is doubtful if any theory of hearing will be satisfactory unless it begins with the assumption that the cochlea as a whole responds to sound vibrations. Any analysis of the auditory sensations that occur is probably made in the brain and not in the cochlea. It is possible that each sound-picture creates a pattern and makes a composite impression in the cochlea, but it is improbable that the cochlea is an analysis apparatus.

It will be enough to tell the boys that *we do not know* how we hear, that no theory so far put forward is satisfactory, that even a great man like Helmholtz was probably mistaken by appearances, the radiating fibres suggesting to him a musical instrument.

THE REFRACTION OF LIGHT.—Approach this subject by first giving instances of retarded velocity: a toy trolley running

down a sloping table, the upper half of which is smooth, the lower half covered with baize; a line of soldiers marching on their front over a field, the first part of which has just been mown, the second part being still long grass: if in either case the approach be normal to the line of separation, there is merely retarded velocity; if oblique to the line of separation, the front slews round as well (see Mr. W. E. Cross's book). Show that this slewing round is inevitable and is *general*; that therefore it applies to light as to everything else. Let the boy realize from the first that the "bending" of a "ray" is merely due to retardation, in a denser medium, of the whole wave-front. It is asking for future trouble if the sine law is worked out first, and the velocity-ratio is mentioned later as a sort of trivial consequence of this law (and this is often done!).

Show clearly that total refraction never occurs: there is always *some* reflection. And show that refraction into a rarer medium cannot take place unless the angle of incidence is less than a critical angle (again illustrate with the marching line of soldiers).

COLOUR VISION.—I have never yet discovered a Sixth Form boy who could give an intelligible account of colour vision; and I am inclined to think that the difficulties underlying rival hypotheses are greater than can be properly dealt with in ordinary school practice. The Young-Helmholtz-Maxwell trichromatic hypothesis is the best hypothesis covering all the facts known at the time of its enunciation, and Helmholtz himself stated clearly that the hypothesis was *only* an hypothesis and did not claim to be fact. Even down to the present time it has not been found possible to demonstrate the existence of three different kinds of nerve elements corresponding to the three fundamental colour sensations. The theory is loaded with subsidiary hypotheses, many of them quite inconsistent with one another. Still, Professor Peddie's book on *Colour Vision* is an uncompromising acceptance of the theory as a fact, though it does not answer the main objections to the theory.

The rival hypothesis of Herring assumes retinal chemical changes under the influence of light, and it also assumes that white is an independent sensation, and not the secondary result of a mixture of primary sensations. But here again the difficulties in the way of acceptance of the hypothesis seem to be insuperable.

Dr. L. C. Martin's book on *Colour and Methods of Colour Reproduction* gives an admirable and unprejudiced account of the facts and views of different authorities. Professor E. H. Barton puts forward an interesting hypothesis of syntony (sympathetic vibratory response) which seems to explain the chief facts of vision. Helmholtz's *Physiological Optics* will always remain a classic, even if his hypothesis is finally superseded. Professor Michael Foster's *Physiology*, although written as far back as 1891, still gives (in Part IV) the best summary of the whole subject, and selections might well be mastered by Sixth Form boys.

The Rival Hypotheses of Light.—Although the principles of these two hypotheses differ widely (the Newton corpuscular hypothesis and the Huygens-Young-Fresnel-Clerk Maxwell undulatory hypothesis), there is no doubt that both hypotheses were in some way interwoven in Newton's mind. "Do not all fix'd Bodies, when heated beyond a certain degree, emit Light and Shine; and is not this Emission perform'd by the vibrating motions of their parts?" And in Query XVII he again compares the ray of light falling on the surface of some substance to a stone thrown into stagnant water. Still, Newton does not seem to have thought, as Huygens did, of the ray itself as just a travelling wave.

The two hypotheses are well within the understanding of Sixth Form boys, who do, however, sometimes find difficulty in visualizing an electromagnetic wave. And boys are always interested in learning how, when about a century ago the velocity of light in water was measured, and the velocity-ratio in the two media, air and water, therefore became known, the corpuscular hypothesis had to give way to its rival.

On the basis of the electromagnetic hypothesis—a development of the earlier wave hypothesis—a beam of light is recognized as having a certain momentum. Moreover, radioactivity seems to show that the process of radiation as a whole depends in part on the movement of electrons. In the X-ray bulb, for instance, a stream of *electrons*, which is truly a *corpuscular* radiation, strikes a block of metal in the centre of the tube. Energy of radiation is carried outwards through the walls of the tube in the form of X-rays, that is to say of *wave* motions in the æther. When they strike matter, such as the film of a photographic plate, the wave radiation seems to disappear and to be replaced by moving *electrons* which produce all the well-known effects ascribed to X-rays. It seems probable that this mutual play of waves and electrons is carried through the whole realm of radiation. But *we do not know* how the energy of the electron in the X-ray bulb is *transferred by a wave-motion* to an electron in the photographic plate.

Clearly the phenomena of photo-electricity calls for a revival of the corpuscular hypothesis in some form, and relativity is making the same clamant demand. On the other hand, the well-established phenomena of interference cannot be made to square with any form of corpuscular hypothesis.

The problem is to reconcile the two hypotheses. Professor Lorentz's Royal Institution lecture on "The Radiation of Light", given on 1st June, 1923, and Sir J. J. Thomson's Fison Memorial lecture on "The Structure of Light", given in 1925, give indications of a possible means of reconciliation: we probably have to accept both the waves and the corpuscles. But the evidence is rather outside the range of Sixth Form work.

THEORIES OF MAGNETISM.—Boys can understand the theories of last century, those developed by Poisson, Ampère, Weber, Maxwell, Ewing, and Curie. But since the beginning of the present century, when attempts were made by Voigt and J. J. Thomson to outline an electron theory of magnetism, based on the magnetic effects of a moving electron, theoretical develop-

ments have become rather too difficult for inclusion in a school course. Boys cannot appreciate the objective side of the evidence on which the theories of Langevin and Weiss are based. And Honda's later theory of gyroscopic motion of the molecule, to account for diamagnetism and paramagnetism, is decidedly obscure; and after all, more recent evidence suggests that the gyroscopic motions do not arise from *molecular* rotations but from a gyroscopic property of the electron itself. It is probably enough to tell a boy that recent evidence suggests that the ultimate magnetic particle is neither the molecule nor the atom but the electron itself, the electron being not merely an electric charge but a magnetic doublet (magneton). At the present moment, magnetic theory is too obscure, and the experimental evidence on which it is based is too fragmentary, to make its inclusion in a Sixth Form course advisable. Time can better be devoted to something else.

THE ÆTHER.—Beware of befogging a boy's mind by telling him that the hypothesis of an all-pervading æther has been given up. After all, the æther has an honest British ancestry—Newton, Kelvin, Clerk Maxwell, Faraday, Lodge, Larmor. Is it possible to deny that a substratum of *some* kind exists? Light-waves and an electric field seem to demand the displacement of the small parts of *something*, a displacement involving strain with its energy of elastic deformation. When some of our foreign friends and their English disciples describe this as the displacement of varying " space ", they seem to mean something very different from the empty " space " which the term space commonly suggests to us. Fundamental space is, presumably, uniform, the same everywhere. As soon as the qualities of space are made to depend on the presence of adjacent portions of matter, it ceases to be pure space and becomes an interconnecting medium with physical properties. We may as well continue to use the term " æther " as change it to " manifold "; even if we think in terms of relativity, and think of space-time instead of space and time separately, the consequential " four-fold extension " still possesses properties,

and is clearly something quite different from empty " space ". Few school boys will be able to understand the relativity conception of gravitation, and the properties of " space-time " will therefore rarely be a topic for inclusion in a school course. But all boys will require to know something of the all-pervading wave-carrying medium, and the term æther is, for this purpose, to be preferred.

Science teachers are not infrequently asked by boys why wireless rays " bend round the earth ". This is a question which concerns the high-level atmosphere, as well as the æther. Reference may be made to Sir Joseph Larmor's paper read in Oct., 1924, to the Cambridge Philosophical Society, and Professor Fleming's article in *Nature*, 24th Jan., 1925.

Carnot's Cycle and its Applications.—Teachers invariably find this a difficult subject to expound, and, even at the end of their physics course, Sixth Form boys often reveal a very hazy knowledge of parts of the subject; and the reason usually is that they have a too slight practical acquaintance with the steam-engine, and have been introduced to the mathematical treatment of the subject before they really knew the inner physical significance of it.

The following sequence of teaching stages has been found to answer well.

1. It is assumed that the usual elementary course of heat has been done, including change of state, the kinetic theory of gases, heat and work relations, the heat engine, the mechanical equivalent, efficiency of an engine.—Revise if necessary.

2. *More advanced work* may now be taken in hand, e.g. heat and work: an outline of the researches of Rumford, Davy, Joule. First Law of Thermodynamics: W = JH.

3. *The Steam-engine*: a machine for changing the heat of fuel into work. Watt's main improvements on Newcomen's engine: condenser, double-action, expansive working, indicator, slide-valve and eccentric, parallel motion, reversing gear, governor, fly-wheel, crank and connecting-rod.—The boys *must*

be given the opportunity of examining a stationary steam-engine in motion, in order that they may obtain a clear understanding of the practical working of the various parts. Nearly every feature of the modern reciprocating engine is to be found in Watt's later designs. Until the boys understand the general action of an engine, further work is likely to be artificial. In particular, let them learn all they can about the cylinder and condenser, the indicator, and the " working substance ".

4. *Indicator and Indicator Diagram.*—If at all possible, let the boys see an indicator in action.* Disconnect it from the cylinder, and show how the connecting gear of the engine turns the barrel of the indicator and how the pencil then draws the horizontal atmospheric line; then disconnect the gear, but connect up with the cylinder, and show how the pencil draws the vertical line. Now ask the boys what sort of a line will be drawn if both connexions are made. Realizing they are dealing with pressure and volume, they will probably think of a Boyle's law curve, or at least some form of *line*. Now let them *see* the diagram actually drawn, and then ask the working engineer to explain, in his own non-technical language, the significance of the diagram. (It is much better that the engineer's explanation should come before the teacher's.) The engineer will explain that the pressure on the cylinder is constantly *varying*, and that this varying pressure is translated by the indicator to the eye; the cylinder of the indicator and the cylinder of the engine being in communication, the indicator responds exactly to fluctuations of pressure in the engine cylinder. He will also explain how the diagram shows the variation of the steam at every point of the stroke, the cushion-

* Otherwise they will almost certainly fail to realize the full significance of the diagram. Arrangements may usually be made for boys to see an indicator working in the mechanical laboratory of a technical college, where engines are provided for purely instructional purposes. If a teacher can make friends with the works manager of a big local engineering firm, and obtain permission for the boys to be present on the test-bed when an engine is being put through its acceptance tests, or when some defect in the working of an engine is being investigated, light will come to the boys as it can come in no other way.

In any case, instruction *must* be given in the actual methods of recording pressure variations. If nothing but diagrams is available for this purpose, the boys are not likely to understand completely. Still, well-designed and remarkably clear diagrams are now obtainable.

ing, the condition of the slides, whether they are leaky or properly set, whether there is too much or too little lap or lead, whether the ports are closed and opened at the proper time. The indicator tells all the *faults* of the engine, by which its power is impaired.—How the indicator has been improved since Watt's time.

At this stage the teacher should explain how the co-ordinates of each point in the plane of the figure correspond to a definite pressure and volume.

5. *The working substance* and its cycle of operations.

6. *Theory of the Steam-engine*: first notions. Carnot in 1824; Joule in 1843; then Clausius, Rankin, Thomson (Kelvin). Efficiency ratio.

7. *Internal energy of a given mass of gas*.—Joule's law.

8. *Isothermals and Adiabatics*.—Clear distinction essential. What they show in the indicator diagram. The significance of the greater angle of adiabatics than of isothermals to the horizontal, at the points where the two cross.

9. *General Equation of a Perfect Gas*: $pv = RT$.

10. *Carnot's Cycle and the Second Law of Thermodynamics*. —Carnot's ideal reversible engine is imaginary, and impossible to construct. Clear views of the dynamical theory of heat may, however, be obtained from it. The four operations form a cycle, and in them the substance is brought back to the same state as at first. The cycle is geometrically represented by a four-sided figure, bounded on two opposite sides by isothermals and on the other two opposite sides by adiabatics. The conditions are simple: a "perfect" gas is supposed to go through the cycle of changes, alternately isothermal and adiabatic.

But these conditions never exist in practice. We must therefore consider Carnot's cycle with ordinary steam for the working substance, the engine itself still being considered ideal.

We cannot, however, complete the cycle as Carnot's cycle was completed. The existence of a separate condenser makes the fourth stage, that of adiabatic compression, impracticable, though, actually, we do stop the exhaust before the return stroke is complete.

11. *Comparative Study of the Four Indicator Diagrams.*—

(i) Carnot's engine, perfect gas.
(ii) Carnot's engine, ordinary steam.
(iii) Ideal diagram, for steam working expansively.
(iv) Actual diagram, showing behaviour of steam in ordinary cylinder. (The successive pressures represent boiler (*m*), atmospheric (*n*), condenser (*p*), and vacuum (*q*).)

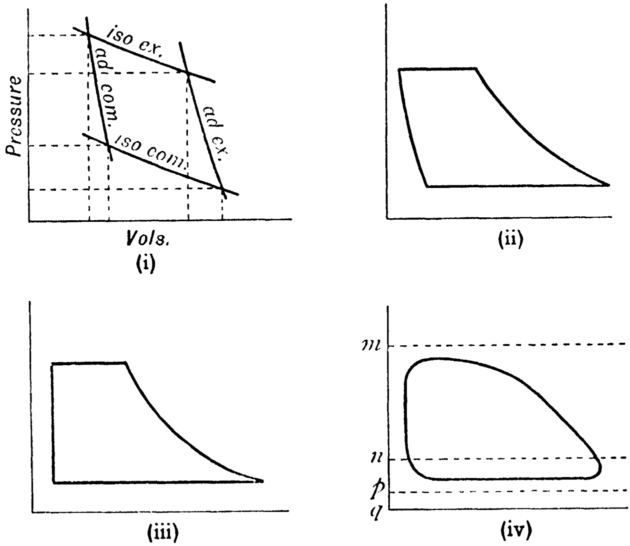


Fig 1

Why, in practice, the diagram has rounded corners as in (iv). The general effects of wire-drawing, and how shown in the diagram. Clearance and cushioning, and their significance.—If the hypothetical engine is clearly understood, the theory of the real engine becomes simple. Do not forget that the influence of the cylinder wall and piston makes a marked difference in the action of the real engine as compared with the Carnot engine, in that they are not non-conductors.

12. The remaining stages need give little trouble: (1) absolute scale of temperature; (2) entropy; (3) formal mathematical considerations.

The laws of thermodynamics should not be taught as if they were finally settled dogmas. They must still be regarded as hypotheses only. Carnot's ideal heat-engine has been sharply criticized, and Dr. J. S. Haldane is critical of the cycle.

A very suggestive book for teachers to read is *Applied Heat* by Oelschläger and Moss. It deals with heat energy from the standpoint of the practical engineer.*

Tendencies of Modern Physics: Should schools ignore them?

It is evident that modern physics is becoming more and more electromagnetic, discontinuous, and statistical. These things are disconcerting to those who grew accustomed to the great classical conceptions of the second half of the nineteenth century; and now the principle of Relativity, which has certainly come to stay, is more disconcerting still. It is true that the formulæ of Relativity tend to simplify the dynamics of very great velocities and to give a greater unity to physics as a whole, but the introduction of discontinuity into physics —the theory of quanta, for instance—has complicated greatly the explanation of phenomena apparently of the most simple character. Kinetic theories which have been introduced seem to compel us to conceive physico-chemical laws as statistical, from the acceptance of which some minds rebel.

The progress of physics towards electromagnetism is striking. The electromagnetic theory of light unites into a systematized whole the phenomena of both light and electromagnetism. But the tendency to explain physical phenomena by the laws of electromagnetism has now attacked even mechanics, which seemed to be the rock foundation of the old physics. Inertia, the fundamental postulate of mechanics, is now explained in terms of the properties of the electromagnetic field; and Rutherford's work seems to leave us no option.

* When the pupil not only clearly apprehends the point that, the second law being granted, the properties of the actual working substance cut no figure at all, but also *fully realizes the significance of this*, then and not till then is he beginning to know something about Carnot's theorem.

The material atom itself appears to be constituted entirely by charges of electricity, and all physical forces, gravitation alone excepted, seem ultimately reducible to electric and magnetic forces. Of the older physics, only the æther seems to survive, though merely as a phantom of its former self. Even the two great principles which hitherto have governed all physical phenomena, the principle of the conservation of mass and that of the conservation of energy, are melting into one.

Of course it is all a question of one hypothesis superseding another, in the light of new facts. During the last 2000 years, science has had many birthdays, *birthdays*, not mere anniversaries, and on each occasion it has decked itself out in new raiment.

At the demonstration table, it is best to be a little conservative over these things. After all, the " tendencies ", and the new hypotheses, are still in a state of flux. Certainly Form V should be kept within the older boundaries, if only because the newer physics is too difficult for them, save that, in such theory of electricity as is thought to be necessary, the electron will necessarily play an important part. Form VI, on the other hand, ought to know, at least in their second year, something of the work that our great physicists are now doing.

A Lesson on X-rays

Here are a few notes made during the course of a particularly effective lesson given to a class of Sixth Form science boys. The teacher's Röntgen tube and fluorescent screen (the former was of the regulating type, but not water-cooled) cost only a few pounds, but was quite good enough for demonstration purposes. A school not thus equipped can usually get a local radiologist to give a demonstration.

1. The spectrum, visible and invisible, and its 70 octaves of electromagnetic waves, from wireless waves of many miles in length to γ-rays of about 10^{-10} inches. Why " octaves "; their recognition.

2. Diagrammatic view of the spectrum, with the position of the 13 (about) X-ray octaves, ranging from 5×10^{-6} to 5×10^{-10} cm.

3. How X-rays are produced. The Röntgen tube: its special features. Story of the discovery. Radiograms and their interpretation. Dangers of X-rays; prevention.

4. Of the 13 octaves of X-rays, 10 are extremely absorbable; the remaining 3 possess remarkable powers of penetrating matter, and it was this that made Röntgen's discovery 30 years ago so remarkable. Including the γ-rays of radium, we have nearly 6 octaves of radiation with which the science of medical and technical radiology does its work.

5. The phenomena turned to account in the industries and art: (1) the differential absorption of X-rays by matter of different densities; (2) the diffraction of X-rays.

6. Invention of the Coolidge tube and the utilization of high voltages for the more opaque materials (up to 200,000 volts).

7. Uses of radiography in industry: detection of blow-holes in castings, examination of steel welds, the soundness of steel balls intended for ball bearings, the centrality of the cores of golf balls, the test of the fit of a new shoe, the testing of aircraft materials (especially aluminium and timber), the interior detail of opal glass electric lamps, the detection of the forgery of valuable pictures and antiques.

8. Medical radiology: how fractures and growths are located; examination of the alimentary canal (bismuth), and tracing the progress of digestion. How it has been shown from radiograms of mummies that such diseases as rickets, tumours, and pyorrhœa existed in ancient times.

9. X-ray diffraction. Laue's discovery in 1912. Crystal analysis and structure of atoms. The simplicity of X-ray spectra compared with optical spectra. How X-ray absorption spectra and emission spectra may be obtained.

10. The Bragg spectrometer.

CHAPTER XIII

Chemistry

In Close Touch with the World Around

The school chemistry text-books of the eighties and nineties were much alike: a strictly formal treatment was customary from the beginning; the elements and their compounds were studied systematically; and fragments of theory were introduced, more or less relevantly, during the course. Then teachers began to flirt with the heuristic maiden; the work attempted became much more logical; reasoning improved greatly. But very little ground was covered, the theory attempted was of the slenderest, there was too much toying with the history of chemistry, and the work done was primarily a training in method and only secondarily a training in chemistry. In recent years there has been another break away, and some of the newer books are not only models of logical development but they make modern chemistry a really live subject. It is useful to read through Roscoe's book, typical of the older kind; then Shenstone's, one of the first to stress quantitative work; then Alexander Smith's, one of the best for the step-to-step development of chemical theory from the practical work actually done; then Mr. Holmyard's, with its attractive and in some ways rather revolutionary sequence; then Messrs. Dootson and Berry's, with its refreshingly new method of approach. These books are but samples, of course, but they serve to indicate changes made and changes pending.

Such books as Mr. Holmyard's and Alexander Smith's make one important thing particularly clear, and that is that chemical theory is just an appropriate setting for a multitude of facts. And whatever method of teaching chemistry is adopted, the learner must be able to see clearly how every fact and every bit of theory fits into the completed picture.

But although a teacher will always have this picture in mind, and will always plan out his course in such a way as to lead to the establishing, on an experimental basis, of the main principles of chemistry, his selection of material may quite well be given a bias of some kind. A great local industry is almost bound to give colour to the course. Why should Sheffield do the same work as Stoke-on-Trent, Luton the same as Port Sunlight?

Perhaps the teacher is interested in, and has special knowledge of, some particular branch of chemistry. If so, why should he not use that special knowledge, provided that he keeps it within bounds? It may be that he has taken up such a subject as water purification, and water for industrial use; in that case his ordinary lessons on the physical and chemical properties of water might be extended specially for a week or so, and include the consideration of large-scale filtration, aeration, sterilization, and distillation, as well as such topics as sources of impurities, corrosion, &c. Or, he may have done special work, perhaps research, on the fixation of nitrogen, or on explosives, or on the liquefaction of gases and the manufacture of liquid air, or on alloys and the metallurgy of iron and steel, or on silica and glass, or on alumina and porcelain, or on illuminants, or on food adulteration, or on the manufacture of artificial silk, or on one of a score of other things. Why should he not make this special knowledge a radiating centre for some of his teaching? But it must be kept in a proper perspective. The danger of such special knowledge is that it gets out of hand; the advantage is that it is knowledge which the teacher has really mastered and is therefore alive.

However the course is mapped out, every opportunity should be taken to illuminate and illustrate principles from the facts of everyday life. A lesson on sulphur would hardly be complete without reference to vulcanized rubber, black gunpowder, fruit-tree spray, and the laxative sulphates; or on phosphorus, without reference to matches, the sodium salt of phosphoric acid used in medicine, and superphosphates used in agriculture; or on arsenic, without reference to insecticides; or on mercury,

without reference to the two chlorides—the poisonous disinfectant and the purgative. And so generally. And every course of chemistry should include something more than passing reference to the triumphs of recent chemical research—artificial silk, stainless steel, chemically tanned leather, synthetic dyes, synthetic petrol, synthetic rubber, synthetic camphor (and the manufacture of celluloid), &c.

Organic Chemistry

The old and rather artificial dividing line between inorganic and organic chemistry is tending to fade away, and a certain amount of work from the latter branch of the subject is now being included in most quite elementary courses. Whether organic chemistry can be profitably taken up as a substantive branch of a two years' course in chemistry for the Sixth Form is a question about which teachers are not in agreement. It is agreed that enough ought to be done to throw light upon the constitution of some of the more complex molecules, and to make possible an intelligent understanding of our great industrial processes. But it is a matter of great doubt whether the greater part of the academic development of organic chemistry, as given in the ordinary text-books, is really worth doing in schools. Its educational possibilities are very limited, and as mere knowledge it is knowledge only for the elect.

Not the least important thing for a boy to understand is that although an organic molecule may be large and very complex, an organic reaction usually involves only a small part of the molecule, and attention must be directed to that small part; also that the reactive part of the molecule is a *characteristic group*, and that it is on the basis of such groups that organic compounds are classified. Probably it is enough to develop ideas of such classification only to this extent: (1) deal briefly with the two great classes of organic compounds, viz. the aliphatic compounds in which the carbon atoms are linked together as open chains, and the aromatic compounds in which the carbon atoms are linked together as closed rings; and

(2) demonstrate clearly the principles of subdivision into hydrocarbons, alcohols, aldehydes, ketones, acids, ethers, esters, and amines. If the subject is taken far enough formally to illustrate the main characteristics of these groups, formal work may then well give place to topics of a more interesting character. But some attention must be given to carbohydrates, if only because plant photosynthesis requires it. It is, however, doubtful wisdom to devote time to proteins and fats; so far as those things can profitably be taken, they are best made part of a physiology course, when digestion, metabolism, vitamins, and dietary requirements are taken up.

Whatever form is given to the introductory course in organic chemistry, it may usefully lead up to elementary considerations of such industrial processes as the following:

1. *Coal-tar Products.*—The following facts ought to be known. (*a*) 1 ton of bituminous coal distilled at 1100° yields about 11,000 c. ft. of gas, 1 cwt. of coal-tar, 13 or 14 cwt. of coke, 3 or 4 gall. of light oil, and 4 or 5 lb. of NH_3 gas (as a liquor). (*b*) The coal tar itself yields, at successive distillation:

(i) At 170°, *light oil* (from which is derived benzene, naphtha, carbolic acid, toluene, &c.).
(ii) At 210°, *middle oil* (derivatives = aspirin, phenacetin, lysol, dyes, &c.).
(iii) At 240°, *heavy oil* (creosote, &c.).
(iv) At 270°, *green oil* (anthracene, &c.).
(v) Pitch (for roofings, waterproofings, coatings, &c.).

A sort of genealogical tree, more complete than this summary, is worth constructing and putting on the lecture-room wall. A certain amount of illustrative demonstration-table work is easily possible and desirable. So also is a little laboratory work.

2. *Laundering.*—This subject makes a strong appeal to girls. (The theory of washing assumes that all dirt adheres to fabrics because of a film of fatty substance, and that only when the latter is removed is it possible for the dirt particles

to be removed and carried away by the suds. Opinions differ as to how the film is destroyed. Beware of dogma here.)

3. *Perfumes, Flavourings, &c.*—An interesting classification of the origins of fragrances and essential oils may be made: from *flowers* (carnation, lavender, rose, violet); from *leaves* and *stems* (geranium, verbena, peppermint); from *bark* (cinnamon); from *wood* (camphor, cedar, sandal); from *rhizomes* (ginger, orris); from *fruit* (lemon, lime, orange); from *seeds* and *berries* (almond, clove, nutmeg). Boys are surprised to learn that ancient and modern processes of distillation differ but little. Steam distillation on a small scale (steam passed through a mass of finely divided flowers, herbs, &c.) is easily possible for demonstration purposes.

4. *Rubber and Related Gums.*—Crude rubber. Physical and chemical properties. Methods of coagulation, washing, drying, milling, &c. Vulcanization. Synthetic rubber. Botany and geography: main facts.

5. *Dyestuffs and their Applications.*—Textile colouring and printing. Dyeing, staining, fixing. Mordants. Classification of dyestuffs.

6. *Cellulose Industries.*—Raw materials, properties. Solvents: reactions. Derivatives: mercerized fibre, vegetable parchment, artificial silk, lamp filaments, bronzing solutions, enamels, photographic films, celluloid or xylonite and its many uses. Explosives.

7. *Evaporated Foods and Condensed Foods.*—Dehydration and dehydrators. Theory of air drying. Vacuum drying. Preparation of foods. Scope of the industry: milk, eggs, vegetable, fish.

If industrial processes, inorganic or organic, are to be dealt with effectively, a lesson or two must be devoted to such large-scale general operations as grinding and crushing; rolls and mills; grading, sifting, and screening; sedimentation and filtration; centrifugal machines, vacuum dryers, lixiviation, crystallization, calcination, reverberatory furnaces, and kilns; evaporation and distillation; conveyance of solids, liquids, and

gases; elevating liquids; refrigeration; the hydraulic press. These processes and the machinery used are common to many industries and are easily explained or illustrated. But do not spend much time either on these things or on teaching the details of the large-scale manufacture of the common acids and of chlorine and its allied products. A few minutes at the end of a lesson would suffice to outline a manufacturing process, illustrated if possible by pictures and sectional diagrams. The details of such processes are of little permanent interest or value.

Undue digression is always a source of possible danger. The work in hand must have a definite aim. Facts must be linked together and principles worked out. A thousand interesting facts may be given to a class, all more or less related to chemistry, but only very slightly related to one another. The facts may be useful knowledge, but such teaching must not be called either *science* teaching or science *teaching*.

Practical Work in Organic and Physical Chemistry

Whether much time can wisely be given by boys to laboratory work in organic chemistry is open to some doubt. Some of the time might perhaps be more profitably spent in getting the boys interested in what research chemists are doing. Organic chemists have not confined themselves to reconstructing natural substances. They have built up hundreds of thousands of compounds * not found in nature. At the present time there are numerous developments in the direction of producing substances needed for particular purposes: it may be required to change the colour, odour, or boiling-point of a substance, and yet to retain its other qualities; to produce an anæsthetic, or other drug, avoiding some of the disadvantages of the substance already in use. How chemists set to work to do these things is always of great interest to boys.

It is of little purpose to let boys spend much time over

* See Beilstein's *Handbuch*. While many of these substances have obtained for their discoverers the Ph.D. degree, they are never likely to serve any other purpose!

organic preparations, though occasionally I have seen excellent work of this sort done; e.g. the preparation of ethyl acetate, methyl oxalate, and chloroform, from following the instructions in some such book as Dr. Cohen's. But, as a rule, both time and materials are sadly wasted over such work. One or two easy "estimation" exercises, say of C, of H, and of N, are of much greater value, but perhaps the practical work of greatest value is the determination of molecular weights: vapour-density method, freezing-point method, and boiling-point method. Suggestive laboratory exercises of a varied and valuable kind are, however, to be found in Dr. Dunstan's little book, a book which makes a preliminary and fairly detailed study of alcohol the jumping-off ground for teaching elementary organic chemistry.

It is probably on the side of physical chemistry that the most valuable form of practical work for advanced boys may be found. Vapour-density determinations (Victor Meyer's, Dumas's, and Hofmann's methods) require a good deal of manipulative skill, and they teach much. Mr. Holmyard's instructions for carrying out these experiments are admirable. In fact, his selection of experiments in physical chemistry is particularly good. No course of physical chemistry is complete if it does not include considerations of the causes of the beginning of a reaction, chemical equilibrium and reversible reactions, solutions and osmotic phenomena, and electrolytic dissociation. It is, however, true that the necessary experiments will often be the business of the teacher at the demonstration table rather than of the boys in the laboratory. An experiment performed must have a *purpose*, perhaps the elucidation of a principle. An experiment beyond a boy's skill is bound to fail in such purpose. (Mr. W. H. Barrett's book is full of useful suggestions for experimental work.)

Occasional Re-grouping of Topics

Suppose it is decided to make *combustion* the general subject of a term's work for an Upper Form, and that the following

topics be jotted down to be included: flame and different types of gas-burners, the manufacture of coal-gas, explosions in coal-mines, low-temperature carbonization, fractional distillation of crude petroleum, acetylene, signal fires at sea, glazing and vitrification, self-ignition of haystacks, and of coal on board ship, and iron smelting.—Is it worth while to detach these topics from the more general subjects in which they are normally included? It is *always* worth while to group facts anew, and to show their manifold relations. But a fresh grouping needs careful handling; the facts must be on a logical string, and that string must be obvious throughout. In this case, the grouping would be, in the main, carbon and its oxides, coal, the hydrocarbons, illuminants, flame, furnaces, fractional distillation. The hydrocarbons form a big subject, of course, but it would not be necessary to include here more than an elementary study of, say, methane, ethylene, acetylene, and one or two others.

Chemical Theory

In view of the ever-increasing mass of facts in chemistry, many of them of the highest importance, what should be the future position of chemical *theory* in our teaching? Should it be given a subordinate position? should it be omitted altogether?

Either of these courses would mean that chemistry would cease to be a science. The facts are the bricks, theory is the cement, of the whole edifice. The facts without the theory are just a heap of bricks, not a building. Theory *must* be taught, but it must be taught in such a way that learners can see clearly how its successive points emerge from our method of classifying facts.

The centre of public interest at the present day lies in the new discoveries and hypotheses of physics—the structure of the atom, the theory of relativity, the theory of quanta, the existence of the æther, the results of the examination of crystals by means of X-rays. There is relatively little public curiosity in regard to the advance of chemistry; a little in dyes and in

poison gas, perhaps; hardly any in agricultural chemistry, the most important branch of all from the national point of view.

Some authorities are of opinion that chemistry is fated to become a branch of physics, and to lose its own peculiar discipline. Our knowledge of the internal structure of the atom has advanced with such rapidity that chemistry certainly may, in time, become a deductive science. But that time is not yet. Chemistry is still an experimental science yielding conclusions by inductions from observed facts, and most of its long-established hypotheses still survive merely as hypotheses and nothing more.

And yet our confidence in these hypotheses is increasing. Why?

Consider Dalton's hypothesis. Dalton's atoms were purely imaginary. They were used to explain known facts and to predict new facts. Nobody claimed them to have a real existence. But gradually the conception of atoms and molecules was found to fit a larger and larger field of facts; confidence grew, and molecules with their families of atoms tended to become real, and the discovery of radioactivity confirmed, to an extraordinary degree, the theoretical view advanced a century before. Not only so, but the study of the films of fatty acids and similar substances on the surface of water has shown that the properties of such films can be accounted for only by asserting the reality of those chains of atoms which had previously been hypothetically assumed to exist in order to explain the structure of organic compounds. The experimental confirmation of the hexagon formula for benzene was a particularly great triumph. Finally, there is the tetrahedral arrangement around a carbon atom, devised to explain optical isomerism. Modern X-ray methods show that the structure of crystals of corresponding substances is fully accounted for by assuming that the benzene hexagon and the tetrahedral carbon linking are actually present.

Since the atom, the molecule, the chains and linkings represented in the graphic formulæ of organic compounds, the hexagonal ring in aromatic substances, and the tetrahedral carbon

atom, were all first invented merely as working hypotheses for co-ordinating groups of experimental facts, and since their actual physical existence seems now to have been confirmed by entirely independent means, ought we to tell pupils dogmatically that atoms, molecules, and the rest are now known to have an objective existence?

The answer is in the negative. Let the teacher safeguard himself by saying " there is now good reason to believe that " atoms really exist. After all, the evidence is still very largely inferential, and the final conclusion is due to many lines of different evidence all gradually converging to one point, some of these lines consisting of both facts and hypotheses, but the whole mass of evidence proving well-nigh irresistible. It must be remembered that pupils are not in a position to marshal all the evidence, or even to grasp its significance when marshalled for them. It is a sound working rule not to advance an hypothesis until the available facts warrant it. Teachers cannot be too insistent in telling their pupils to be cautious about drawing deductions from the evidence obtained from experiments. There is always a danger that the beginner will assume that the facts depend upon theory instead of theory upon the facts. The pupil *must* know his facts first.

In a well-known standard text-book on chemistry, the author, discussing the theory of electrolytic dissociation, says: "The facts can not only be interpreted by means of this theory, but are a necessary consequence of it." The second part of the statement implies that the facts occur as a mere consequence of a pre-existing theory. Such a statement is grotesque. Had the author said that new facts had emerged from an investigation undertaken on the strength of the assumption that the theory was true, his statement would have been acceptable.

What principle is most fundamental in all chemistry work? What facts form the basis of our performance and interpretation of every chemical experiment?

Is it the atomic hypothesis? Chemistry teachers used to think so, but they were teachers of an age that is past.

Is it the principle of definite proportions? This presupposes

the conception of compounds, and the idea of elements and compounds is therefore more fundamental.

Is this idea of elements and compounds the answer to our first question? No, for we cannot recognize a compound except by obtaining from it two or more substances with properties which distinguish them from one another and from the parent substance.

It is these *distinguishing properties* that give us an answer to our question.

The basis of all chemical work, then, is the fact that *each substance has its own set of physical properties by means of which the substance is recognized* and by the use of which the substance is separated from other substances when necessary. The main object of every experiment is *to produce new physical phenomena for purposes of observation*, and to discuss these observations in terms of physical realities.

At what stage may the atomic hypothesis most usefully be introduced? The answer is, when we have accumulated the particular set of facts the hypothesis was primarily designed to explain. The central fact of that particular set was that the proportions by weight in which a given element enters into all sorts of combinations may always be expressed by a fixed number, or by whole multiples of this fixed number. Hence, the hypothesis should be introduced when experiments dealing with combining proportion by weight have been performed, and the results are discussed. In other words, it should be introduced for explaining the quantitative laws of chemical combination.

May it be used at an earlier stage, for instance to explain the bare facts of chemical combination and the qualitative features associated with it?—Consider the simple case of the combination of Cu and S to form CuS. The boy knows the properties of Cu and of S, and he *expects* the properties of the combined mass to be a sort of average of those properties. But he finds they are wholly different. Will this new mystery be cleared up if he is told to think of the Cu as consisting of tiny bits (atoms) and the S as consisting of tiny bits, and of

each tiny bit of Cu becoming attached to a tiny bit of S; and that when the tiny bits are attached in this way, the properties of the united little bits will be entirely unrelated to those of the previously separate little bits? Is an intelligent boy expected to believe that the rearrangement of these invented and imagined little bits can explain changes of properties? Would the boy not be justified in telling his teacher to tell that story to his grandmother?

How can the atomic hypothesis, as commonly presented to beginners, adequately explain the nature of the tendency to combine, or the mode of combination, or the new properties of the product of combination, or the heat developed during the process of combination, or indeed *anything* save the possession, by each element, of a special unit of weight which it employs in all its combinations?

If we invite a beginner to believe as a fact that diverse atoms become united in pairs, and that the properties of the combinations are unrelated to those of the constituents, and if we invite him to associate those two inconsistent ideas every time substances are combined in the laboratory, shall we not, as a result of persistent suggestion, finally hypnotize him into a frame of mind in which logical consistency is no longer a test of credibility? Is it surprising that the intelligent layman sometimes scoffs at " scientific " reasoning?

Let the teacher say as little as possible about the relation of the atomic hypothesis to those things which it was not primarily devised to explain.

Observation and *experiment* are the only method of obtaining facts, and no facts can be safely obtained either by inferences from, or by interpretation of, laws. Observation in chemistry consists in noting *the specific physical properties of substances*, as revealed by experiments.

Very little theory should be attempted until after the great generalizations of chemistry have been established on an experimental basis—the laws of constant, multiple, and reciprocal proportions and the law of Gay-Lussac. Dalton's hypothesis and Avogadro's hypothesis are now necessary to *explain*

the groupings that led to these laws, and theoretical considerations must therefore now step in. As the work advances, the atomic theory is further and further developed.

There is no objection to the comparatively early use of formulæ and equations, if it be made clear that they are merely a shorthand registration of experimental results, and nothing more. Early in the course they can have no real quantitative significance.

Valency is a subject which often gives trouble to beginners. It should give none if its experimental basis is made clear—that it is simply a consequence of the choice, from amongst possible combining weights, of the particular atomic weight.

If organic chemistry is formally included in the school course, to what extent should the theory of the subject be pursued? The answer leaves little room for doubt. It should be pursued just far enough to enable the learner to understand the broad principles underlying the grouping of organic compounds. The boys must have clear notions of stereo-isomerism, and, generally, of the architecture of the organic molecule. But do not conceal the few things that really matter, and they are very few, behind a smoke screen of those elaborate formulæ so dear to the heart of the expert chemist.

It may be well to remember that, into the great industries which have been founded by chemistry, and into the practitioner's day-by-day analytical work, the atomic theory as such hardly enters. Chemistry as an *art* can be taught without any reference to the atomic theory. But chemistry as a *science* is on a different footing, for here its processes have to be placed on a rational and consistently logical basis. And it is chemistry as a science which is the chemistry of schools. In schools we teach chemistry partly for its own sake but also, at least equally, for the sake of the almost unequalled intellectual discipline which the subject, as a science, exacts from its followers.

Still More Snags

1. Physics in Chemical Experimentation.—Admittedly all chemical observation consists simply in the noting of physical occurrences, and in interpreting them in accordance with physical principles. Curiously enough those parts of physics which are most needed in chemistry are precisely those which receive but little attention in the average physics course prescribed for schools.

A boy is told, say, *to heat* $KClO_3$, to observe what happens, and to record his observations. The boy writes down: "The substance melted, and then it boiled." How can we find fault with him for assuming that the action is similar to the action of the heating of ice? Outwardly, to the untrained observer, the appearances are at first much the same. Why should the boy continue with the heating of the chlorate, unless he is told to do so? Why should he not assume that, if the boiling is continued, the substance will disappear much in the same way as water disappears? Or, if he has had previous experience of water of crystallization, why should he not assume that the substance has "melted" in its own water of crystallization? If by chance he observed that the agitation of the liquid did not cease when the flame was removed, he might begin to suspect that he was not dealing with a case of simple boiling, *provided that he was already familiar with the nature of boiling*. The changes in the consistency of the material would puzzle him, and as for the giving off of oxygen, why should he suspect it? Clearly the boy should have been given detailed directions, but the experiment presupposes that a boy has been already trained *to recognize and to understand the phenomenon of ebullition*.

Again, how is a pupil to study the action of *strong HCl on iron and copper*, unless he knows the distinction between the boiling of a liquid, the evolution of a gas from a solution (both of which might happen in the case of copper), and the evolution of hydrogen (which will occur with the iron)?

Again, pupils often find difficulty in *distinguishing gases*

from solids and liquids. They do not know that gases do not disperse light but transmit it, and thus they think that the fog issuing from a locomotive is entirely gaseous. A familiarity with the relations of matter to the dispersion of light is essential to the understanding of many experiments in chemistry that involve the production of fumes of some kind. The same field of knowledge is involved in understanding the difference between solution and suspension.

How is a pupil to understand that, say, P_2O_5 is not a gas, if, the first time the phenomenon is encountered, the behaviour of the substance is not compared carefully with that of a gas?

Again, consider the experiment of *burning hydrogen in air* to form water. Extinguish the jet, and hold a cold beaker against the jet of unlighted gas; moisture is still formed. This always puzzles a class of boys. Some will suggest that the water comes from the combination of the hydrogen with the oxygen in the air, showing that they have failed to realize the significance of *lighting* the jet. Others will suggest that it arises from condensation of moisture in the atmosphere, though they cannot explain this. Only rarely will a boy give the real reason—that the flask contained a liquid which was warm and consisted largely of water through which hydrogen was passing and that therefore the issuing gas consisted of a mixture of hydrogen and water vapour. Beginners are not likely to realize that the gas must be dried if the experiment is to be fair. The lesson is so valuable that the thoughtful teacher will *not* dry the gas until the lesson has been learnt.

Thus it all comes round to this—that a course of elementary physics *must* precede chemistry. All chemical experimentation involves the observation of new physical phenomena, and in order to recognize these phenomena pupils must have had a suitable previous training. A good deal of incidental instruction in physics will, however, necessarily accompany every chemistry course, though such instruction will be less of a formal kind than that of a kind which consists in drawing attention to the fact that the work in progress involves the application of certain physical principles already taught.

2. Inadequate Laboratory Directions.—In a certain "laboratory companion", the following exercise is given: "Write down what you observe when concentrated sulphuric acid acts on crystals of potassium iodide."—Such directions are altogether inadequate, and failure is inevitable. The pupil ought to be told to powder the crystals, just moisten with the acid, and warm. But, even so, the result is bound to baffle him. He observes fumes in the air outside the mouth of the tube, a violet-coloured vapour inside the tube, a brown film on the walls of the tube, an odour (SO_2 or H_2S or both), and perhaps a yellow sublimate (sulphur). Unless he is warned he may assume that one body has all these properties. Without detailed guidance, he will never realize that from three to five different products have resulted from the action, and certainly he may not yet have met with some of them. The directions should be given in much greater detail in order that an investigation may be made systematically. But such an experiment would be unsuitable unless the pupil had previous knowledge of the properties of the different substances resulting from the action.

In any chemistry course, the succession of experiments should, as nearly as possible, form a natural sequence. A boy might, for instance, be legitimately asked how he would separate a mixture of H and CO_2 *provided* he was already familiar with the properties of the two gases. He ought then to be able to suggest one or more ways of removing one of the constituents of the mixture. A well-taught pupil should be able to "think chemically", and apply his knowledge in a rational manner. Such a pupil will see, when a piece of sodium is thrown upon water, something more than the antics of the metal.

3. Neglected Opportunities for Illustrating Chemical Action.—A whole lesson is sometimes kept too strictly within severely academic limits. Whenever possible, borrow illustrations from everyday life and illustrations from technical processes. For instance, illustrate oxidation by the way in which paint dries through the absorption of oxygen by the

solidifying oil; reduction, by photographic developers; reversible actions, by the storage battery; osmotic pressure, by root pressure in plants; dissociation of the reversible kind, by lime-burning; displacement of metals, by toning in photography; solution, by alloys. And so generally.

4. QUALITATIVE ANALYSIS.—The possible educational value of this work is much reduced by the present-day tendency to neglect preliminary "dry tests". These tests, especially for the identification of single substances, may afford the learner so much evidence that the subsequent "wet" work is little more than confirmatory and may be quickly done. Heating on charcoal, heating in bulb tubes, perhaps heating with concentrated H_2SO_4, borax bead tests, ignition on platinum wire, sublimation, all these and several others of like kind give the pupil a knowledge in which he soon feels great confidence. Valuable clues, if nothing more, almost always emerge from these tests, and the time for the complete analysis is greatly reduced. I have often seen pupils, who had been well trained in this preliminary work, obtain correctly in a very short time the several constituents of a mixture commonly thought to be "difficult", whereas other pupils who depended entirely on their "wet" separation tables took much longer and were seldom altogether successful.

5. GRAVIMETRIC VERSUS VOLUMETRIC WORK.—In his *Practical Chemistry*, Mr. Holmyard devotes fifty-three experiments (41 pp.) to volumetric analysis, and only three (4 pp.) to gravimetric analysis. I am not very happy about this proportion. Mr. Holmyard says that gravimetric analysis "is not so convenient as volumetric analysis and requires considerably more skill; it is therefore a very good training for the young student, and should on no account be omitted. At the same time the operations are often rather lengthy."

On several occasions I have given a class the same estimation exercise to do, half to do it volumetrically, half to do it gravimetrically, and I have invariably found that the latter had by

far the clearer understanding of the problem in hand. There seems to be a greater simplicity about gravimetric methods, a simplicity which inspires greater confidence in the final result. And some of the older text-books on quantitative analysis, Professor Thorpe's and Mr. Newth's, for instance, leave nothing to be desired in the lucidity of their detailed instructions for gravimetric analysis. In volumetric work, the simpler titrations soon become at least as mechanical as the much criticized qualitative analysis. Still, volumetric work has its good points, educationally, and it is bound to find an important place in any school chemistry course. Mr. Holmyard's treatment of the subject is all that can be desired. Another admirable little book is that by Mr. J. B. Russell.

6. FORMULÆ.—We have already referred to that invaluable little book *Experimental Proofs of Chemical Theory* by the late Professor Ramsay, and we criticized its method of establishing the Law of Charles. But it has to be borne in mind that a university professor usually writes a book for students already familiar with the elementary parts of the subject. Detailed instructions concerning experiments for establishing principles ought not, therefore, to be necessary, though for beginners such instructions are naturally the normal thing. Thus, if and when this particular book is used in schools, the subject-matter provided has to be considerably supplemented.

An example from Professor Tilden's *Chemical Philosophy* may usefully be considered. The problem is to establish the formula of a compound which, when analysed, gave the following result: C, 37·20 per cent; H, 7·90 per cent; Cl, 54·95 per cent. The author then divides these percentages by the atomic weights, and then each of these quotients by the least quotient (all in accordance with accepted procedure), thus arriving at the formula C_2H_5Cl. As might be expected, the instructions are perfectly sound as far as they go, and doubtless an advanced student would understand the rationale of the whole process. But no hint is given *why* the percentages are divided by the atomic weight, or *why* the three quotients

are divided by the least. An intelligent boy would, if he followed out the instructions, doubtless evaluate the formula, but the work he had done would have no physical significance to him.

Contrast with this a similar problem with explanatory arguments specially provided for school boys. We select Mr. Holmyard's 3rd, 4th, and 5th sections of his chapter on Determination of Formulæ (*Organic Chemistry*). The sections are, calculation of empirical formula, calculation of molecular weight, calculation of true formula. The empirical formula for ethyl alcohol is established, then follow arguments concerning the true formula. The arguments are lucidly set out, and the learner (presumably belonging to a Sixth Form) is able easily to understand what he is about.

7. CATALYSTS.—Do not make the pretence of explaining to beginners such a process as catalytic action. It is enough to tell them that catalysts are speed-modifiers, faster or slower. Hypotheses as to their nature may come later. If physiology is taught, a similar remark will apply to enzymes, which may be regarded as organic catalysts, serving to stimulate chemical reaction involving organic compounds. Ptyalin in saliva and pepsin in gastric juice are common instances.

Logical or Psychological Order?

This question arises in the teaching of all other branches of science, as well as chemistry. It is a good general rule so to arrange the facts to be taught that they are presented in the order of difficulty of comprehension. The ordinary text-book in chemistry often makes H_2O_2 follow close on the heels of H_2O, because of the close relationship in composition. Logically this is defensible enough, but H_2O_2 is a substance differing greatly from water, and the chemical actions illustrating its behaviour are often very complicated. The wise teacher therefore postpones H_2O_2, or even eliminates it entirely. Again, standard text-books commonly classify all the chlorine com-

pounds in one group, and describe them in succession. But the result is quite different when we classify the compounds according to the intrinsic difficulty of understanding the reactions of each. The study of the element chlorine is easy enough, so is the union of chlorine with other elements. But when we reach hypochlorous acid, with its habit of decomposing in three different ways, we have to deal with a topic very much more difficult to understand. It should therefore be postponed.

But, *as far as possible*, the psychological order should be the logical order. If the teacher cuts himself adrift from the logical order, or even very much from the traditional logical order, he is seeking trouble. He should adhere to a logically worked-out system as far as this is consistent with psychological principles, lest his building powers should prove unequal to the task of erecting a structure to take the place of that he has demolished.

The History of Chemistry

No course of school instruction in chemistry is complete unless it includes at least an outline of the history of the subject. Some writers of modern text-books include a good deal of history incidentally. Mr. Holmyard is one. Dr. Bauer's *History of Chemistry* is particularly attractive in that it groups the subject under periods—the chemistry of the ancients, the period of alchemy, medical chemistry, phlogistic chemistry, Lavoisier, developments in organic chemistry, present-day chemistry. Let the teacher always try to group together workers in the same field, e.g. Grotthus, Hittorf, Pfeffer, Ostwald, van t'Hoff, Arrhenius. And do not forget the quarrels of rival schools: how, for instance, Kolbe personally insulted van t'Hoff. Boys like to read about the quarrels of great men of science, and it helps to impress them with the fact that hypotheses are only hypotheses after all. Readers of *Nature* are well aware that there are living men of science who dread the discovery of new facts which will dethrone a pet hypothesis that made them famous years ago.

Another point: never give boys reason to think that all scientific discoveries are due to Englishmen. Think of the great chemists that even Sweden has produced.

Text-books and New Books

The value of a good text-book lies in the fact that it is a source of knowledge arranged systematically. It furnishes a definite record, and enables the pupil to acquire needed information speedily. But any book has its limitations. It omits, and inevitably must omit, the description of a vast number of the physical details which are, after all, the native language of the science, so to speak. This is where the private student is so greatly handicapped.

The chemistry teacher who thinks he can teach his subject merely by transferring the contents of a text-book into the heads of his pupils is under a great delusion. The best book has to be supplemented in a hundred ways.

Books outside the ordinary text-books, especially books with a human interest, must be recognized as playing a necessary part of a pupil's training in chemistry. For instance, Davy's and Faraday's accounts of their own researches are always of the greatest interest to boys, and, incidentally, the boys learn much from them, especially about methods of investigation. From the point of view of interest, such books are on a par with the best detective stories. They *are* detective stories.

Always keep a look-out for new books written by well-known teachers, even though you may decide you will not adopt them. Such books nearly always contain something worth learning, some new point of view, something unconventional, something rather contrary to accepted traditions, something a little provocative. The new book by Messrs. Dootson and Berry, for instance, is full of new points. The chapter on the ionic theory is particularly good, and such minor matters as the extreme sub-divisibility of matter, and the superior limit of molecular dimensions are treated in such a way as to make an immediate appeal to the learner. Many teachers will be

inclined to argue, perhaps hotly, about some of the methods of presentation, but a book that provokes discussion is always useful. Some of Mr. Holmyard's methods are bound to provoke discussion: so much the better. We are all apt to lean a little too heavily on tradition; that way safety lies—so we unconsciously argue.

Keep in the school library such books as Dr. Philip's *Romance of Modern Chemistry*, Arrhenius's *Chemistry in Modern Life*, Rogers's *Industrial Chemistry for Students and Manufacturers*, and let boys refer to them for special points—to illustrate principles, to suggest new applications, to see a thing from another point of view. Such books are not written on traditional lines, and on that very account are specially valuable. Another excellent work of reference is Tilden's *Discovery and Invention in the Twentieth Century*. Teachers who know nothing of American universities will have something of a shock when they read in this book an account of, say, the extent of the chemistry buildings and of the professorial staff in the University of Illinois.

Every teacher of chemistry should read Professor Armstrong's article on chemistry in the 1926 edition of the *Encyclopædia Britannica*. It throws more light on the inner nature of the whole subject than any standard work I have read. In particular, a teacher may glean from it many useful hints as to the best method of approach to organic chemistry.

Laboratory First-aid

Accidents will happen, and the chemistry teacher must always be prepared for emergencies. Let him keep a special cupboard for first-aid appliances, and, pasted up in the cupboard, a plainly written list of the commoner accidents and the remedies to be applied. The cupboard should contain bandages, lint, boric wool, oiled silk, court plaster, scissors, solution of iodine, boric acid solution, boric acid powder, sodium bicarbonate, carbolic acid, picric acid (for powdering over a phosphorus burn, after cleansing with a weak wash of carbolic),

ammonium hydrate, alcohol (for inhaling the vapour, after chlorine or bromine irritation), and a clean wash-bottle with clean water frequently renewed. The contents of the cupboard should be kept exclusively for use in accidents that may occur in the laboratory or lecture-room. The key of the cupboard should remain in the lock whenever the laboratory is in use, and it should be somebody's special business to see that this is done. It is always advisable for the chemistry teacher to submit his first-aid scheme to the school medical officer. That way lies safety.

All pupils may be instructed thus far: the first-aid remedy for burns caused by acids and alkalies is *neutralization*. For acid burns, wash with water and apply solution of a weak base, say sodium carbonate, or, if this is not available, then lime water or dilute ammonia solution; for alkali burns, wash with water and apply solution of a weak acid, either saturated boric acid or very weak acetic acid.

Remember that first-aid is *only* first-aid. Unless the accident is trifling, the patient should be sent off at once to a surgeon. Actions at law are apt to be unpleasant, no matter how careful the teacher may have been, no matter how careless and disobedient an injured boy may have been.

Terminology

Give pupils the origin of such terms as *ethyl*, i.e. et(her)hyl; *amine*, am(monia)ine; *aldehyde*, al(cohol)dehyd(rogen); *acetone*, acet(ic)one. A score of Greek roots will explain a hundred terms. But chemists cannot be forgiven for adopting such bastard terms as *ester* and *ketone*.

CHAPTER XIV

Biology

The Neglect of Biological Teaching

It behoves all science teachers to help educate public opinion as to the vital importance of a knowledge of biology. As a branch of science, biology is, even now, commonly associated with a perfunctory and amateurish study of an emasculated botany, a harmless hobby suitable for children and slow-witted girls, not a virile discipline for the intellectual girl and boy. Biology as a subject for the adolescent connotes something very much more than what is commonly known as " Nature Study ".

The Report of the Prime Minister's Committee emphasized the need for the inclusion of biology in every secondary school course. It was considered that the ground to be covered before the age of 16 should include, first, the main facts as to the relations of plants and animals to their surroundings, and as to the changes in material and in energy involved in their life and growth; secondly, the main anatomical features of the higher plants, the elementary physiology of plants, and some quite general knowledge of animal metabolism. Between 16 and 18, systematic work in zoology, including the dissection of animals and the use of the compound microscope, might, the report suggested, form a suitable basis for the work to be done.

The Committee of British Zoologists, in their draft report on the position of animal biology in the school curriculum, urged that the general aim of school studies in biology should be to inculcate a sound appreciation of the natural laws which govern the lives of human beings no less truly than they do those of other animals and of plants; that the basis of the study should be close observation of plants and animals in

relation to their natural environment and not as self-contained entities; and that morphological study should be undertaken less for its own sake than for that of its fundamental importance in the study of organic function. The committee suggested that the work of the lower Forms should consist mainly of direct observational study of living plants and animals; that in the middle Forms it should be correlated with elementary physics and chemistry; that a special feature should be made of simple experiments illustrating the fundamental processes of respiration, assimilation, &c., in plants and animals alike, and that their essential similarity to the corresponding processes in the human subject should be emphasized, and that the idea of evolution should be implicit; that in the higher Forms (pupils above 16), biological work might be conducted along the separate lines of botany and zoology, and more detailed morphological study be undertaken in both, but that the greatest importance should, throughout, be attached to the elucidation of the functioning of organs and of the organism as a whole.

All this is most admirable advice, but it might perhaps have been given with greater emphasis. The past general neglect of biological study in secondary schools largely explains why the cultivated classes of the country are so ignorant of biological principles. Comparatively few educated people have a grasp of those principles, even of the principles which are most directly related to human welfare and right living. Fewer still seem to be aware how the laws of heredity are now recognized as of vital importance, not only for increasing and improving supplies of agricultural products but for human life itself. It is undeniable that men aspiring to a place in national, or even local, leadership ought to have a firm grasp of all available knowledge of those laws which underlie human life and human evolution. They ought also to understand what an enormously important part biological science plays in the modern civilized state. The provision of food for the community—crop-raising, stock-breeding, the production of dairy products, fisheries, the preservation of food by canning and freezing, and so on—is obviously an immensely complicated

system of applications of biological science. So also with the maintenance of the health of the community—the prevention of disease, the war on parasitic microbes, and the cure of disease by the modern methods of medicine and surgery—those are also obviously applications of biological science.

Main Principles of Biological Instruction

But all these things are mere applications of principles to be taught in a course of school biology. In drafting such a course, what are the main principles to be kept in view? On this there is general agreement thus far: (1) the great fact of evolution and its far-reaching implications, especially the struggle for existence in nature and the elimination of the unfit; (2) the great fact of inheritance—the fact that the child repeats the characters of the parent, physical, mental, and moral, but that this repetition is never so complete as to amount to identity as regards such characters; (3) the biology of communal life, both as presented by communities of social insects such as bees and ants, and as presented by cell communities constituting the bodies of the higher animals. It is of the utmost importance for the pupil to understand the three great principles of communal evolution: (1) increase in the size of the community; (2) increased specialization of its constituent individuals; (3) increased perfection of the organization, by which the constituent individuals are knit together into the communal individuality of a higher order. *Then*, but not before, the pupil may appropriately approach the study of human society, where the same principles are at work, and evolution still proceeding.

When a teacher is drafting a biological course, all these principles will be kept steadily in view. But they are not principles which will appear in the early lessons; rather they form the general aim and purpose of the course as a whole. The course completed, the principles will have been worked out. During the actual working out of the course, necessary facts will be accumulated, and subsidiary principles will be established.

The planning out of a course to meet these requirements is exceedingly difficult, especially if it is to be as exacting as a course in physics or chemistry. The subject is so big, the available time so little. Clearly it is not possible to do more than make a small selection from the vast number of known facts, a selection nothing like great enough for generalizations to be based on them, but enough to illustrate and typify. There is consequently always the danger that the teaching may tend to become dogmatic, and yet, of all the subjects taught in school, biology is the very last to be doled out as unassailable dogma. Biological theory is seldom more than an affair of possibilities; rarer, of probabilities. Occasionally a biological hypothesis receives universal acceptance; much more often it is tinged with doubt and uncertainty.

Biology a Difficult Subject to Teach

Biology naturally falls into a series of allied studies. These studies are concerned with the characteristics of living organisms, their forms and parts, the various functions which the parts discharge, the physical relations which the forms have with one another and with their environment, their genetic relations, and their geographical distribution. Living organisms seem to have the power of self-maintenance, and the power of preserving an individuality. A living organism takes nutriment, grows, and reproduces itself.

For investigation purposes, we are driven to treat the living organism as a physico-chemical mechanism, though of course the organism is something much more than the sum of all its parts and their physico-chemical relations; it is a unified and purposeful individual. Every organism (unicellular organisms excepted) is an association of cells, each cell living its independent life but each contributing in some special way to the life and maintenance of the organism as an individual whole. This is one of the first things for a pupil clearly to understand.

How the physical and the psychical are related in an organism we do not know. That they *are* related is certain.

The change in the moral character of a man is sometimes the effect of a brain-lesion due to a blow on the head; bad news may bring about a psychical disturbance which results in a marked physical disturbance of the body, temporary or permanent. But the relationship is an unsolved mystery.

As far as we can tell, an animal which has just died is chemically identical with what it was when alive. It serves no good purpose to " explain " things by the supposed presence in a living organism of a " vital force ", of an " entelechy ", or of some other imaginary, elusive, responsible, working principle. It is much more honest to tell the pupil that *we don't know.* Abstain from talking to pupils about materialism, vitalism, or any other -ism. The teacher's business is to explain *how* living things act and to say candidly that he does not know *why* they so act.

The experimental difficulties in biology are great. The extreme complexity of structure and of function of the living organism makes it very difficult to isolate any particular part we wish to examine. Such isolation is usually possible in physics and chemistry, but in biology the simplest experiment is complicated by the fact that the thing being experimented with is *alive*, with the consequent possibility of the presence of all sorts of unsuspected disturbing factors.

Always impress upon pupils the fact that the great majority of the vast number of ascertained facts in biology, and many of the great generalizations, are not the results of work done in the laboratory but of work done outside it—the work of the great naturalists who as travellers have examined living organisms, their habits, distribution, and environment, all on a large scale. Darwin and Wallace are examples. Pupils cannot understand too clearly how a biologist is, first of all, an outdoor naturalist. The effect of a too exclusive occupation with laboratory experimental work tends to be narrowing, though its importance cannot be over-emphasized. We cannot but respect a man who devotes a life-time to the study of, say, the neurology of the *Aphides*, but to call him a biologist is to stretch courtesy almost to the breaking-point.

Biology as a Group of Allied Studies

The first and most obvious division of biology is into the two studies of plants and animals, BOTANY and ZOOLOGY, respectively. The broad distinction for pupils to note between plants and animals is that plants contain chlorophyll and cellulose, and make their own starch and sugar, while most animals have to depend, directly or indirectly, upon plants for their food. But both plants and animals may be considered from two points of view: (1) that of the *anatomist* who dissects out the large-scale organs, and the *histologist* who examines the minute tissues; both are interested in the *forms* of animals and plants as wholes, in structures, connexions, positions. Their subject is MORPHOLOGY: it is the static side of biology. (2) That of the *physiologist*, who deals with the dynamic side of biology, the aspect expressed by the term *function*—the study of the activity of the various organs, the activities of tissues, the active life of individual cells, the metabolism of the protoplasm. Thus morphology is contrasted with PHYSIOLOGY.

To the study of morphology belongs the study of anatomy and histology of extinct species, termed PALÆONTOLOGY.

Then, again, we have the study of the early stages in the growth of the organism, its organs, and its tissues. This study, EMBRYOLOGY, includes both the morphology and the physiology of the developing organism.

Both palæontology and embryology are in close relation with the racial and evolutionary aspects of biology.

Then, again, although life is limited to the individual, it is continued in the race, and this suggests the studies of EVOLUTION and HEREDITY.

The study of the diseases of organisms has for its basis the subject of BACTERIOLOGY.

Both morphology and physiology will naturally be included in any course of either botany or zoology.

All the biology that is likely to be taught in schools will thus be included under these headings: botany, zoology, human physiology, embryology, palæontology, evolution, here-

dity, bacteriology, and these form the subjects of the next few chapters.

Genetics is virtually another term for heredity. *Ecology*, the relation of organisms to their environment, should be treated as an ordinary section of botany and of zoology. So should the geographical distribution of animals.

The greatest advance in biology in recent years has been made in the study of the cell. In fact, biologists are now beginning to think of life in terms of cells, and they are concentrating their attention on the process of cell division, feeling sure that wonderful secrets lie buried there. The genetical process of division is the central phenomenon of physiology, and is perhaps the key to variation and heredity.

Pupils should know something of the lives of the great naturalists and biologists—Linnæus, Cuvier, Buffon, Owen, Lamarck, Mendel, Darwin, Wallace, Huxley, Pasteur, Weismann, and others.

Schools which cannot find time for the study of the separate subjects considered in the next few chapters should take up a course of a more general kind. For this purpose there is no better book than Haldane and Huxley's *Animal Biology*. The writers, who are, of course, eminent authorities on the subject, have packed into some 340 pages the essentials of all branches of the subject. They describe things remarkably clearly, and their illustrations are so good that there is no difficulty whatever in following up their argument. But teachers who take up a general course of this kind should remember all along that plant and animal life form the two complementary halves of a single subject, and that from the outset both must receive attention.

Before proceeding with the chapters on the subdivisions of biology, we must deal with the general question of biological classification and terminology.

CHAPTER XV

Biological Classification and Terminology

Main Principles of Biological Classification

Ask a boy if he can classify " races of men " logically, in accordance with the common usage of the term *race*—the white race, the Latin race, the Irish race, and so on; and thus lead him to see how unscientific the common assumption is that race is an affair of pigmentation of the skin, or of religion, or of geographical position, or of temperament. Show him that criteria of race are necessarily physical, including, in particular, such morphological features as the shape and proportions of the head, the qualities of the hair, skin, nose, and eyes, stature, and so forth. But since no bodily characters are wholly exempt from adaptive modifications, there does not seem to be any single characteristic that absolutely marks off one race from another. And even if we could classify men satisfactorily in this way, there would certainly not be any corresponding association of mental characters, and no racial, mental, or moral superiority in any one. Obviously no strictly logical classification of races of men is possible. And yet it is universally agreed that man has characteristics separating him off distinctly from all other animals. Apparently, then, animal grouping is not altogether impossible.

Boys do not hesitate to put into a single class all the known varieties of dogs, and to distinguish them clearly from cats, though they may not be able to say that the main *specific* differences between dogs and cats concern teeth and claws. Similarly they can distinguish between horses and asses, though they may not know that the main specific differences concern callosities and tails. The first thing for learners to understand in biological classification is *specific differences*, in order that they may obtain a clear idea of a *species*.

But they must also learn that occasionally the amount of

difference between parent and offspring is so strongly marked that the offspring may receive the name of variety; that it is often difficult to decide whether groups of similar forms should be ranked as species or as varieties, and that intermediate forms give rise to doubt; and that when a new animal is discovered, there is often a difficulty about coming to a decision concerning the species in which to place him, and that he may even have to be regarded as a member of a hitherto unknown species.

The next thing for the learner to grasp is that the basis of specific differences is homological, not analogical. Homology expresses morphological, structural, architectural, developmental, similarities; analogy, merely the functional resemblance between the parts of different animals. Homologous structures reveal a deep-seated resemblance in build and in manner of development. Zoological classification seeks to show the blood-relationship of animals, because it is believed that all groups showing homological similarities really had, in some remote age, the same common ancestor, and such classification is therefore based on comparative anatomy, though much help is also obtained from embryology and palæontology. Boys soon understand why whales must not be classed with fishes, or bats with birds.

The biologist no longer believes in the fixity of a species. On the contrary, he believes that one form has given rise to another. The specific characters should exhibit a certain degree of constancy from one generation to another. No very great difference is likely to be seen in a hundred generations, or even in a thousand unless by special breeding.

Explain to the pupils that biologists no longer attempt to define species by the method *per genus et differentiam*, but by *type*. The difficulty of defining is due to the absence of clear-cut grouping.

The next point for the teacher to take up is the various grades of classification, based on degrees of resemblance. The main principles are easily taught and always quickly understood, the successive groupings making a strong appeal to

boys. Thus species are grouped into genera, genera into families, and then into orders, classes, and phyla. Give one or two simple examples to be memorized, e.g.:

Individual—my dog Peter.
Variety—fox terrier.
Species—domestic dog (*Canis familiaris*).
Genus—Canis.
Family—Canidæ (dog-like carnivora).
Order—Carnivora (flesh-eating mammals).
Class—Mammalia (vertebrates that suckle young).
Phylum—Vertebrata (animals with bony skeletons).

Each main division is called a *phylum*, and includes animals built on the same fundamental plan and believed to be descended from one ancestral stock.

Nomenclature

One of the first things for pupils to learn is the biologist's recognized system of *naming* animals and plants. The name always consists of two parts: (1) the name of the *genus* (a capital initial letter is always used; (2) the name of the *species*; e.g. *Canis familiaris*, *Acer rubrum* (the red maple). The name of a variety is added as a third name, e.g. *Acer rubrum drummondii*. These names are in universal use, and are found in the text-books of all the nations—a great advantage.

Classification in School Work

Anything like a strictly logical and exhaustive classification of animals is quite outside the range of any course of zoology that may be taken in schools. But the main characteristics of the principal phyla should be familiar to a Sixth Form boy (the Protozoa, Porifera, Cœlenterata, " Worms ", Echinodermata, Arthropoda, Mollusca, Vertebrata. Some knowledge of the five classes of the vertebrates (Fish, Amphibians, Reptiles, Birds, Mammals) should be given, and a few of the best-known orders and families of each of these five classes should be

known, more especially those of the mammals. By the time a boy has completed his course of zoology, he should be able to assign any animal studied to its proper place in the zoologist's genealogical tree. He will then be able to take up evolution intelligently. But during the main course of zoological teaching, it is neither necessary nor desirable to introduce minutiæ of classification. It would only serve to obscure things of much greater importance. Still, the *principles* of classifying should be understood.

In botany, Sixth Form pupils should be familiar with the distinctive characteristics of the four great Phyla, and with those of the main divisions of the fourth:

1. *Thallophyta* (algæ, fungi, lichens).
2. *Bryophyta* (mosses, liverworts).
3. *Pteridophyta* (ferns and their allies).
4. *Spermaphyta*, viz.
   (*a*) Gymnosperms (conifers, &c.).
   (*b*) Angiosperms, viz:
      (i) Monocotyledons.
      (ii) Dicotyledons.

The *principles* underlying the classification of dicotyledons will generally have been taught in forms below the Sixth. It is quite enough even for Sixth Form pupils to be familiar with just a few "orders". Do not waste time over unessentials.

Biological Terminology

This is always forbidding to a layman unless the layman knows something of Greek, and then he will grasp the inner significance of the meaning of a term more readily than the average biologist himself. To some biologists a biological term is just a label for tying on to a particular thing, and to him *abracadabra* would do just as well as *prosenchyma*. It is desirable that, from the first, teachers of biology should make their pupils hunt out from the dictionary the origin of every new biological term introduced. By a rational grouping of words, the memory is helped enormously: e.g.

arthro*pod*	hydro*zoa*	blasto*derm*	bio*genesis*	*arthro*pod
cephalo*pod*	meta*zoa*	ecto*derm*	epi*genesis*	*arthro*derm
gastero*pod*	poly*zoa*	endo*derm*	pan*genesis*	*arthro*pterus
myrio*pod*	proto*zoa*	echino*derm*	partheno*genesis*	*arthro*zoa

and so generally. A hundred biological terms may hang upon less than a score of common Greek words (they are usually Greek), and, in nine cases out of ten, the term is derived from *two* Greek words, e.g. we have polyzoa, protozoa, protoplasm, ectoplasm, ectoderm, blastoderm, blastula, and so on, almost indefinitely. Some readers may be surprised if they make out a list of ordinary biological terms derived from these few very common Greeks words: *ἄρθρον, βίος, βλαστός, βρύον, γάμος, γαστήρ, γένεσις, δέρμα, ἐκτός, ἔνδον, ζῷον, θαλλός, κεφαλή, πούς (ποδ-), πρῶτος, πτερίς, σπέρμα, σπορά, σῶμα, φύλλον, φῦλον, φυτόν.*

There is a curious tendency to confuse *phylon*, *phyllon*, and *phyton*.

Biological teachers should see that their pupils pronounce the terms properly. It is a common thing to hear wrong accentuation, e.g. the stressing of the penult instead of the antepenult, as in *parenchyma*.

CHAPTER XVI

Botany

Experiments Essential from the Outset

A standard work in botany written by an English professor about thirty years ago devoted just three times as much space to plant classification as to plant physiology. It would not be altogether unjust to say that such a book made three times as great an appeal to the memory as to the intelligence. In teaching botany, experimentation *must* be given a foremost place.

There is one great difference between school experiments

in botany and those in physics and chemistry, and that is that the former may extend over several days or even weeks. Evidently it is an advantage for several experiments to be in progress simultaneously. The pupils make periodical observations of each, recording and dating these on separate pages of their note-books, for discussion later. A great deal of school time is often wasted because the experimental work in botany is badly organized. The fact that the problem of organizing courses in experimental botany has its special difficulties must be faced; the problem must be thought out.

In justice to himself the botany teacher should remember that nearly all plant physiology experiments, even in the hands of expert botanists, are seldom more than partially successful; and that adequate evidence for the purpose of logical reasoning is often difficult to obtain.

The Earlier Work in Botany

The earlier work in botany, though simple, should aim at the experimental discovery of important general facts about plants; for instance, that the root absorbs water containing dissolved substances, and passes it up the stem; that the stem conducts such water from the roots to the leaves; that the leaves spread out into the light, and that water is evaporated from them; that all living plants need oxygen, just as animals do, and, like them, give off CO_2 (never mind the reverse process in photosynthesis, at this early stage); and that the growth of the plant is promoted by warmth and moisture. The pupils will probably already have *some* knowledge of these things, but their vague knowledge must be converted into certain and exact knowledge.

Telling work on such a subject as the germination of seeds may be done by quite young pupils, as we have already pointed out. The work is so important that we may refer to it again.

Necessary directions for observation and experiment can be easily drafted, and most of the work left to the pupils. The usual box with a side of glass sloping inwardly, damp chopped

sphagnum and blotting-paper, a few small boxes of different kinds of soil, are nearly all that is required. Each pupil makes daily observations and records. Some such scheme as the following would meet the case:

1. Germinate seeds at different depths; other conditions to be the same.

2. Germinate seeds at different temperatures (keep one box in a cold room, one in a room at normal temperature, one in a hothouse temperature); all other conditions to be the same.

3. Germinate seeds under different conditions of moisture—in dry soil, in moist soil, in saturated soil. (In the last, the roots may come up to the surface, to get air.)

Three or four different kinds of seeds should be used for each of the above experiments.

4. Note how the seed-coats burst in different seeds.

5. Note how the embryos break out of the soil.

6. Try to grow seeds in an airtight glass jar containing a little pyrogallic acid (place seeds on a moist sponge suspended to cork).

7. Grow equal weights of mustard seed under exactly similar conditions, but one in light, and one in the dark. Dry, weigh, and compare the weights now.

8. Observe the growth of the *roots* of seedlings. Mark with india-ink rings, 1 mm. apart.

9. Observe the growth of the *stem* of seedlings, marking as before.

10. Note *direction* of growth of root and stem. Place growing seedlings in horizontal and other positions, and find out what part of the root bends in turning downwards.

11. Cut off the tips of some roots, and note what happens.

12. Record amount of growth of root and of stem day by day.

Of course such directions are not full enough for young pupils, and a teacher would have to elaborate them very considerably. The work might continue until the seedlings are well developed. The important thing is to vary one condition at a time. Good reasoning is then possible.

Sixth Form Work

Sixth Form work generally covers School Certificate work carried to a higher standard, and, in addition, such topics as the following:

1. Some knowledge of the external morphology and the main anatomical features of a few common dicotyledonous trees and conifers.

2. A certain amount of comparative morphology and biology.

3. Tissue structure.

4. Plant ecology.

5. Flowerless plants.—The structure, life history, and habitat of certain types, and especially the comparison of the different genera from the point of view of the differentiation of the plant-body, the different methods of sexual and asexual reproduction, and other aspects of plant evolution.

(i) Flagellata—*Euglena.*

(ii) Algæ — *Chlamydomona, Protococcus, Spirogyra, Vaucheria, Fucus.*

(iii) Fungi—*Agaricus, Mucor, Eurotium, Saccaromyces, Bacillus.* (The part played by Fungi in plant disease.)

(iv) Pteridophyta—*Lastrea* (*Aspidium*), *Selaginella, Lycopodium.*

6. Plant physiology: some quantitative relations.

7. Elementary considerations of evolution and genetics.

The two main things are the plant physiology and the work with the microscope. Second-year Sixth Form pupils should be fairly proficient in their physiology experiments, and should have acquired reasonable skill in the use of the microscope.

Pupils should be taught how and what they can learn from the microscope, and be made to understand that the microscope is not just a useful instrument for verifying other people's work. They should practise cutting transverse and longitudinal sections until they can cut them well, and they must learn how to use the common reagents, and so gain a knowledge of the appearance and the reactions of the parts of the cell and of some of the bodies commonly contained in it—the cell-wall, the protoplasm and nucleus, starch, chloroplasts, and so on.

Naked-eye observation of a bulk of tissue easily handled should precede the work with the microscope. Take, for instance, five or six inches of the stem of a well-grown sunflower plant, cut a longitudinal section through a node, and dissect

out the course of the several vascular bundles; trace the course of the several bundles entering from the leaves. Get a first *rough* idea of plant structure in this way. (A good deal of work of this kind will, presumably, have been done in the middle Forms.)

Now examine the vascular system of a young seedling of the sunflower by means of a succession of transverse sections, examined in proper order under the microscope. By comparing the sections, it is possible to reconstruct in the mind the whole shoot from which the sections were cut, and this is the important thing for the pupil to learn. He must not look upon a section as a mere network of cell walls, but as a slice of tissue which had a certain definite position in the plant from which it was cut.

Let him now cut sections of two or three new stems or roots, and discover for himself the structure of the contained vascular systems. At first he will find it difficult to interpret the story that the different sections tell him, to visualize the whole of the internal structure of the plant. But a little practice will do much. When his eye has had the preliminary training, then and only then can he profitably begin systematic work with the microscope.

A beginner's longitudinal (radial and tangential) sections are often cut obliquely, with the result that his reconstructed mental picture is hopelessly confused.

Pupils' drawings of their own sections must be well executed. To be of any real value, these *must* be followed up by an intelligent interpretation.

School Gardens

One enterprising London school (the James Allen School for Girls) has been developing its gardens for over thirty years, and every botany teacher should see them. They originated in a few Order beds which included leguminosæ and solanaceæ, for it was considered advisable, even in those early days, to make London acquainted with the growing of vegetables. Special

plots were arranged for pollination experiments and for photosynthesis experiments. Flowers were left to form fruits, and various methods of seed dispersal were studied. As the school soil consisted of London clay, chalk soil was brought from Surrey, sea sand from Lowestoft, soil from salt marshes at Gravesend and Burnham-on-Crouch, all for the purpose of growing special types of plants. A heath was also planted; so was a wood which now contains several hundred trees; so was a lane 160 feet long, consisting of a grass walk 8 feet wide, bordered on either side by hedgerows and ditches. The school is now in possession of a heath 100 feet by 40 feet, a sand dune, a pond 34 feet by 23 feet; a salt marsh, two fresh-water marshes, a peat bog, and many other valuable features. The work of the gardens is designed to serve the purpose of making botany a real science. A large number of experiments are carried out, and a wealth of plants is available for the purpose. The botany is taught as it should be taught—in the garden and in the laboratory.

Few schools could compete with this particular school. Neither is it necessary for country schools to take so much trouble: woods, lanes, hedges, ponds, heaths, marshes, are often easily available. But in large towns school gardens are of the very greatest value.

Such operations as grafting and budding may usefully be done in the school garden. But care must be taken not to allow the main subject, botany, to be overshadowed by horticulture. After all, gardening is not a science—yet.

Rambles and Excursions

These are not always successful, and sometimes they are wholly unprofitable. A few members of a party are usually interested, especially if the responsible teacher is a keen naturalist, but the majority tend to chat about trifles, perhaps pick a few flowers—and probably throw them away at the end of the day. The work to be done on an excursion must be properly organized. Either the teacher must take the lead,

draw attention to the things to be observed, and see that notes and sketches are systematically made; or small batches of pupils should be told off to co-operate in doing certain types of work, it may be on the ripening of fruits, or on the dispersal of seeds, or on defences against the hot sun or frost. Things observed should be described, not merely named. It is a good plan to make the same excursion two or three times, at intervals, marking down plants of special interest to be examined and re-examined. In that way much may be learnt.

By-ways in Botany

If time could be found for them, all sorts of interesting topics might be included in a botany course, especially topics of economic interest. For instance, it is known that 10 per cent of the world's crops are lost annually through the depredation of insects, and a large percentage of the empire's crops are lost annually through the encroachment of noxious weeds. Thirty million acres in Australia are put out of action by the prickly pear, and huge areas of cultivable land in New Zealand are going under to the blackberry and bracken fern. To boys it is an unforgettable fact that in the south island of New Zealand there is a current saying on the west coast that they have a blackberry bush 200 miles long. Facts like this stir up the boys' interest in economic entomology. The story of the successful world hunt for a plant-feeding insect that would eat up the prickly pear and not eat up anything else, and the present hunt for an insect that will feed exclusively on the blackberry, are stories to awaken interest in a new branch of knowledge of great economic importance.

Another thing always interesting to pupils is poisonous plants. They like to know that cattle always avoid foxgloves and daffodils, apparently fearing them instinctively; and yet the cattle are not wise enough to avoid the meadow saffron or ragwort. The ignorance of children as to the harmful nature of common plants is profound—the attractive-looking fruit of the deadly nightshade, the berries of the yew, the seeds of the

common laburnum, the enticing seed-pods of *Arum maculatum* (" lords and ladies "), ivy berries, the " currants " of the common laurel, the pasque-flower, cow parsley. Then again, children should avoid handling the primrose called *obconica*, some daffodils, and some ivies. The caper spurge exudes an obnoxious milky sap. A list of poisonous plants should be given to all children learning botany.

The Ministry of Agriculture issue a useful pamphlet, " Poisonous Plants on the Farm ".

Final Snags

1. Control Experiments.—An experiment is often undertaken to discover the relation between some function of a plant and some particular external condition, and we try to observe the effect upon the plant when that condition is removed or neutralized. But different conditions are often so closely associated that the removal or neutralization of a single condition is difficult, perhaps not possible. To help make sure that the result obtained is really connected with the condition selected, and not with some secondary influence introduced by the manipulation in the experiment, it is usually necessary, and always advisable, to try at the same time a parallel experiment, in which a similar plant is placed under precisely the same external and experimental conditions as the first plant, except that the particular selected condition is not changed. Thus, in both experiments, all the conditions save one are the same; the difference is only in the particular selected condition. Hence it is a fair inference that an observed effect is connected with the change in the selected condition. Such a parallel experiment is called a " control ". The term is not a good one, though its intended meaning is clear. Such an experiment helps to check the accuracy of the facts from which we draw an inference, but it is a common thing to find children with a very hazy idea as to its purpose.

A fruitful source of error in control experiments is due to the fact that no two plants are exactly alike and their behaviour

is probably never quite the same. Even in the same plant no two parts are exactly alike, and the variation, no matter how small, may give rise to experimental differences which may lead to unsuspected errors. Hence, in control experiments, selected plants should not only be of the same stock, or at least as near akin as possible, but the two roots, or shoots, or leaves, should be from the same plant; or, better still, the leaves or other parts should be from the same shoot; or, still better, the two corresponding parts should be from the same leaf or other organ. In this way the possibility of error is reduced to a minimum. The difference in the age of the plants, and even of the parts of plants, is especially liable to introduce serious error.

2. Culture Solutions.—These fail more commonly than not. Success may reasonably be expected if the following precautions are taken: (1) Guard against "damping off"; (2) darken the roots; (3) add water each day to replace that evaporated; (4) once a month, take out the plants, wash the roots, place in plain water for two days, then in a fresh culture solution; (5) see that the solution is not alkaline; (6) force air into the solution daily. Here is a good culture solution: 2 gm. of calcium nitrate, ½ gm. each of potassium nitrate, magnesium sulphate, and potassium phosphate, a drop or two of iron chloride, in 4 or 5 litres of distilled water.

3. Respiration.—Loose reasoning and unsatisfactory experiments on respiration are common. For beginners, Professor Ganong's experiment is as good as any. His respiroscope consists of an inverted U-tube, one end being corked, the cork supporting a small wad of miost sphagnum on which rests, say, a few soaked oats, and the other end being open. Three such tubes are prepared. Three large test-tubes are also wanted, large enough for the open limbs of the U-tubes to slide in freely with a little room to spare. These test-tubes are half filled, one with a strong solution of caustic potash, one with a concentrated mixture of pyrogallic acid and caustic potash, and one with water.

The pupils must already have learnt that carbon dioxide is readily absorbed by caustic potash, and oxygen by a mixture of pyrogallic acid and caustic potash.

The discussion that would follow the experimental results would probably take the following sequence:

(1) The pyrogallic acid solution in a short time rises in the U-tube about one-fifth of its length, the oxygen being absorbed. The seeds do not germinate.

(2) In the potash-tube the liquid rises to the same height, but more slowly; the seeds germinate, and grow considerably. The seeds absorb the oxygen and give off the carbon dioxide which is absorbed by the potash, and the potash rises to occupy the space left.

(3) But this potash-tube result does not *prove* that anything is given off, since the rise of the liquid is accounted for by the removal of the oxygen. All that the experiment proves is that something is absorbed, doubtless oxygen from the air by the seeds. But the third tube helps us here:

(4) In the water-tube, the seeds germinate and grow as in the potash-tube, but the water rises in the tube scarcely at all, showing that a gas is given off as well as absorbed; and since the only gas absorbed by potash is carbon dioxide, that gas must be given off in volume equal to the oxygen absorbed.

Thus pupils learn from the experiment that oxygen seems to be necessary to growth, that carbon dioxide seems to be given off during growth, and that the volumes of gas thus exchanged are equal.

(It is a good plan to show in a preliminary experiment that germinating seeds really give off carbon dioxide, by placing in a closed bottle a number of soaked seeds with a small dish of clear lime-water. After two or three days the turbidity of the lime-water indicates the presence of carbon dioxide.)

Germinating seeds are selected instead of a green plant in order that the experiment may not be complicated by the opposition and reverse process of exchange of oxygen and carbon dioxide in photosynthesis.

Of course the whole experiment is of a very rough and

ready kind, and, for advanced pupils, various refinements are necessary. As a quantitative experiment, it is of little value, if only because the rise of the liquids in the tubes cannot possibly mark the extent of the absorption. Allowance has to be made for pressure and temperature differences, and the gases have to be tested. In short, a crude respiroscope cannot be used as a respirometer.

But the beginner does learn from the experiment the essential thing about plant respiration. And the close analogy with animal respiration should always be pointed out.

4. PHOTOSYNTHESIS.—It is assumed that pupils have already learnt from the usual experiments that, for photosynthesis to proceed, carbon dioxide, water, light, and chlorophyll are all essential; that he knows that carbon dioxide and water are the initial products, and sugar and starch the final products.—The real trouble now begins.

The " photosynthetic equation ", viz.

$$6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2,$$

may be allowed to stand, but the intermediate equation, showing, first, the formation of formaldehyde from CO_2 and H_2O, and secondly, the formation of sugar from formaldehyde, must be given as mere possibilities. It is dangerous to enunciate any sort of final dogma concerning photosynthesis; the subject is still controversial.

The pupils should be made to realize the far-reaching importance of this process of photosynthesis. The green plant is the basis of the food supply of all living animals, including man, because of its remarkable power of building up, in the presence of sunlight, sugar from water and the carbon dioxide of the air. The sugars and the other carbohydrates formed from them are reservoirs of energy which, in the form of food, enable animals to do work. But the chemical and physical details of the photosynthetic process are not fully known.

Formaldehyde is actually found in green leaves, and has

long been considered to be an intermediate photosynthetic product. Hence when the late Benjamin Moore succeeded in synthesizing formaldehyde from CO_2 and OH_2, using for the purpose the energy of light, the assumption that the same process took place in the green leaf seemed to be confirmed. A few years later, Professor Baly succeeded in the next step, viz. in converting formaldehyde into sugar, using the energy of ultra-violet light.

But Professor Baly has since demonstrated that CO_2 (with OH_2) may be converted *directly* into sugar, O being given off during the process, formaldehyde not forming a stage in the synthesis. Then what is the origin of the formaldehyde in the leaf? Is it an intermediate synthetic product, or is it a mere by-product due to the disintegration of carbohydrates already formed? *We do not know*, and pupils must be told this.*

Warn the pupils of the danger of drawing illegitimate inferences from the achievement of organic photosynthesis in the laboratory. It does not at all follow that, because we have succeeded in manufacturing thousands of organic compounds, we shall ever succeed in making a living thing. A plant or animal that has just been killed contains, presumably, just the same organic compounds as before, but we do not know how to make these compounds " live " again. When once a functioning green leaf has been put together artificially, then indeed will a miracle have been worked.

Impress pupils with the need of being very cautious in arguing about these things, on the ground that our knowledge of them is only slight.

5. THE TRANSPIRATION CURRENT.—It is assumed that the pupil knows something about diffusion and osmosis, and something about the entrance of water into tissues despite increasing hydrostatic pressure; that he has learnt how the stem is a means of communication between root and leaves and that he can visualize the communicating channels; that he has

* Professor Baly's most recent researches into photosynthesis are summarized in a Royal Institution Discourse which he delivered on Feb. 3, 1928.

learnt that only a small portion of the water absorbed by the root-hairs is absorbed osmotically by neighbouring cells, and that by far the larger part travels as a *current* from root to leaves where it is *transpired*; that he has learnt that this transpiration current does not break, no matter how rapid the transpiration, and that, if the current ceases to flow, transpiration stops. Then the pupil ought to have no difficulty in understanding that since the current does not break, and since it may rise to the top of the tallest trees (say 300 feet), there must be a great force at work to push it up.

The root-pressure resulting from the osmotic absorption of water is wholly inadequate as an explanation, especially as root-pressure cannot be detected in many plants, and in none when transpiration is active. How, then, is the upward moving current of water to be explained?

One common experiment is to soak a piece of parchment membrane in water and tie it tightly over the wide end of a thistle funnel, to fill the funnel completely with boiled and cooled (and therefore air-free) water, to close the narrow open end with the finger, and, holding the tube thistle-end upwards, to plunge the open end in a basin of mercury. Of course water gradually evaporates from the parchment surface and the mercury rises up the tube. The explanation sometimes gravely put forward is that the parchment surface is like the transpiring leaf surface, and that the mercury is " lifted " or " pulled up " the thistle funnel tube in exactly the same way as the transpiration current is lifted or pulled up the tree. Both, so it is said, are the simple result of the evaporation of the water.

The explanation is just as absurd as Herodotus's explanation of the Nile floods—that they were due to the sun " drawing " the water.

Even a Third Form boy ought to see at once that the mercury rises in the tube because of the outside atmospheric pressure; the atmospheric pressure is able thus to show itself because of the diminishing water pressure. If the experiment is done in a vacuum, or, better still, if the tube used in the

open exceeds 33 or 34 inches in length, the experiment fails; or rather the experiment shows conclusively that the limited rise of the mercury was due exclusively to atmospheric pressure. It throws no light whatever on the rise of a transpiration current.

If no tree exceeded the height of about 34 feet, the inference that the rise of the current is due to atmospheric pressure would perhaps be justifiable from the facts known. That we now know the inference to be wrong serves to show how, in the absence of sufficient evidence, an explanation may be entirely misleading.

No hypothesis yet put forward in explanation of the rise of the transpiration current is quite satisfactory. Not one squares with *all* the known facts.*

We do not know, and this the pupil must be told frankly.

It is this baffling nature of many of the processes of plant physiology that makes some competent authorities doubt whether botany is a suitable subject of science for schools. As a subject for purposes of observation, it stands perhaps first; as a subject for experiment, it is full of very serious difficulties. Experiments are rarely quite satisfactory, and inferences from them are often seriously inaccurate, even when the rules of logic are carefully observed.

Dr. Wager, F.R.S., is the chief authority on botany teaching in this country, and his remarkably lucid way of putting things will be familiar to all teachers who have read his articles in the successive editions of the *Encyclopædia Britannica.* Teachers of botany who find themselves in difficulties over particular points should consult him, and those who are able to attend one of his summer courses for teachers should certainly do so.

* In *Nature* for Aug. 4, 1928, there is an interesting letter from Professor Molisch of Vienna, describing experiments on sap movement, as designed by Sir J. C. Bose. The results seem to show conclusively that the movement is not due either to a root-pressure push from below or to "suction from above" by transpiring leaves. There seems to be an inherent activity in the stem itself independent of the activities in the terminal organs. The movement seems to be less strictly physical than physiological, the flow apparently being pulsatory; the pulsation may be markedly increased by certain stimulants.

CHAPTER XVII

Zoology

Function rather than Form

For the teacher of zoology, there is now available a wealth of admirable text-books written in consonance with the accepted principles of present-day treatment of the subject. In the older books the usual plan was to devote a chapter to some animal selected as representative of its group (species, order, class, as the case might be), and to make the study of it mainly morphological. *Differences* between one animal and another were stressed, but fundamental *resemblances* were only lightly dealt with. Thus the teaching followed on much the same lines as the teaching of botany. Morphology received chief attention, function but little.

Just as plant physiology is now taking the leading place in the teaching of botany, so it is with animal physiology in the teaching of zoology. There are certain phenomena characteristic of all living animals—growth, reproduction, locomotion, nutrition, respiration, excretion, response to environment; and in any scheme of instruction it is those phenomena that must be given a foremost place, and each be studied comparatively.

There are two text-books on zoology that all teachers of the subject should read, Professor J. Arthur Thomson's and Professor Dakin's.

The first eighty-seven pages of Professor Thomson's book are devoted, first, to a general survey of the animal kingdom, then to elementary considerations of physiology, morphology, embryology, palæontology, and the doctrine of descent. Then follows (pp. 88–836) a systematic study of the whole animal kingdom, phylum by phylum.

The chapter on physiology, dealing with the life-activity and function of animals, considers briefly, but very lucidly,

such topics as nervous activity, muscular activity, digestion, absorption, respiration, and excretion. The resemblances and differences between animals and plants, as regards both structure, function, and development, are happily summarized. The chapter on morphology deals adequately with symmetry and homology; and that on palæontology, with the imperfection of the geological record and with the extinction of types. Altogether, these eight-seven pages are a really excellent introduction to the whole subject. And in the next 748 pages a teacher will find ready to hand all the material he needs for studying selected types. Professor Thomson is recognized as a born teacher as well as a front-rank naturalist.

Professor Dakin makes a rather new departure. His book is a complete justification of the right of zoology to be considered as a suitable experimental subject for school work, and it is certainly an excellent guide to the teacher as to the way in which the relative claims of function and structure may be adequately met. Function is the dominating note of the book, and, except for a chapter on the protozoa, the subject-matter is arranged under the headings of the various functions of animals, and not under the customary systematic groups. In dealing with any one function, the author gives just so much structural detail of the organs concerned as is necessary for a comprehension of their uses. The book is full of excellent suggestions for experimental work, especially experiments for practical demonstrations of the physiological processes underlying function.

In the study of multicellular animals (Metazoa), the author shows clearly how, with the increase of structural complexity, there is a corresponding specialization of parts of the body; how, for instance, as we ascend the animal scale, a special digestive tube running through the animal is developed, and how this necessitates a circulatory system to convey the digested food products to all parts and to carry away waste products; further, how special areas are gradually developed for respiration, and special structures for excretion and reproduction; also, how this increasing differentiation then demands a co-

ordinating system, with the result that a nervous system with controlling centres and sense organs appears, putting everything into touch with the environment. All this is worked out in a way that makes a strong appeal to the reasoning powers; and the animal types selected and the experiments proposed are exactly what the teacher needs for making a series of studies in comparative morphology and comparative physiology.

In the section on *nutrition*, for instance, the food and digestion of the following animals are considered: sheep, frog, fish, crayfish, cockroach, bee, housefly, *ascaris*, *hydra*. Other topics similarly considered are, respiration and respiratory organs, transportation systems, the blood, temperature and animal life, the animal skeleton, animal movements, cells and tissues, the nervous systems and the sense organs, growth and reproduction, life histories, evolution and heredity. In each case the most suitable animals, from lower to higher, are selected, and the increasing functional complexities worked out. Under each topic, a large variety of useful experiments for practical work are suggested.

Many text-books on zoology give useful practical hints for laboratory work but Professor Dakin's hints are particularly valuable, especially for work with the microscope, e.g. fixing, dehydrating, embedding, section-cutting, treatment of sections after cutting, staining, and so on. His instructions for dissection and practical work on common animal types—the earthworm, butterfly, water-beetle, snail, mussel, crayfish, dogfish, frog, rabbit—are full of just those practical tips that the elementary student requires. The instructions direct attention to essentials, and do not distract it by unnecessary minutiæ.

Professor Dakin also gives useful warnings concerning the study of cell-structures, pointing out that what we see under the microscope are usually dead cells, and that some of the things we see may not have existed at all in the living cell. By killing the cell and staining it, it is of course possible to differentiate structures which cannot usually be seen in the living cell, the nucleus having a marked affinity for dyestuffs. It is only

by careful comparison of the results of different methods of treatment, checked when possible by observations on those living cells which happen to allow of certain structures being very favourably seen, that we can be fairly certain of what is natural and what is artificial in what we examine under the microscope.

Early Observational Work

Is it best to begin zoology by considering a Protozoan or a Vertebrate? This is a very old question. And it is a very "nice" question. Do we gain by working upwards from simplicity to complexity, or by first giving details of a complex picture and working downwards to simplicity?

On balance, the arguments seem to be in favour of beginning with a fairly thorough study of a relatively complex animal, say the frog or the rabbit. The subsequent sequence probably matters little, but most teachers will probably prefer to begin again, this time with a Protozoan and then to work systematically upwards.

But before attempting to dissect (say) the frog, observations of the live animal should be made, and it is this kind of work that is so suitable for beginners. For instance:

1. Watch the frog sitting. Note the fore and hind legs. Make the animal jump, and note the way the legs are used in jumping and in landing.
2. Place him in a tank of water and note his movements, especially the use of the webs and the hind limbs. How long does he stay under water? Note his floating attitude if the water is too deep for him to sit on the bottom of the tank.
3. Note his respiratory movements. Try to find out if he can see, feel, or hear.
4. Turn the frog over on his back and note his movements while he is righting himself.
5. Observe his behaviour during feeding. Place him in a covered dish with a little water, and add some live insects. From his behaviour, do you think that the frog sees, hears,

or smells the food? Observe the action of the tongue in capturing the food.

6. Describe the feel of the frog's skin.

7. Kill the frog with chloroform. Describe the head, trunk, and the two pairs of limbs. Note the absence of neck and tail. Describe the nostrils, eyes, the three eyelids, the tympanic membrane posterior to the eye, the mouth opening, and the jaws.

Even when an Upper Form pupil begins the study of a new animal, he should begin, whenever possible, by studying it alive. As an example of a carefully thought out scheme, we give Miss Hymans's directions for examining a live crayfish.

1. Observe the animal's method of walking. Which appendages are used? How are the others held? Can the animal walk sideways or backwards? Make the animal swim. What is the chief swimming movement? Explain the action of the muscles of the abdomen in swimming. Are the pleopods used in swimming? are they kept in motion when not swimming?

2. Observe in a quiet specimen the continued rhythmic movement in certain appendages. Determine which appendages are concerned. (These movements are of a respiratory nature.) With a dropper, place a few drops of carmine suspension near the posterior edge of the bronchial region of the carapace. By the movements of the granules, determine if there are any respiratory currents and in what direction they go.

3. With a glass rod drawn out to a blunt point, touch various parts of the animal and note response. Touch various appendages. Is the response different according to the part touched? Are some regions or appendages more sensitive than others?

4. Drop a piece of fresh raw meat four or five inches from a crayfish. How long before the animal perceives the presence of food? Note its behaviour, and observe the method by which it finds the food. Observe the process of chewing the food, and the use of the various mouth appendages in the process.

Directions of this kind supplied to pupils are almost indispensable. By means of them, the pupils know exactly what to look for and how to set to work systematically. The directions should not *tell* more than is absolutely necessary, or the work may become mere verification of an almost purposeless kind.

The following directions are, on this ground, open to criticism and they require to be redrafted. They tell the observer far too much, and yet the inquiry, if properly directed, is exactly what is wanted. The examination is systematic and exhaustive.

THE EXTERNAL ANATOMY OF THE WASP.—Kill several wasps without mutilating them and mount them in different positions on fine needles thrust into corks. Examine with a hand lens.

1. Observe size, shape, colour, and general anatomy. Body bilaterally symmetrical; dorsal and ventral sides alike, forward and hinder ends unlike. Legs on ventral side, wings on dorsal side.

2. External surface smooth. Animal encased in a hard shell called the *cuticula* which is composed of chitin; it is the skeleton of the animal.

3. Body composed of a number of serially arranged segments. These are the *somites* or *metameres*. The body is sharply divided into three divisions, *head*, *thorax*, and *abdomen*.

4. *Head*, unsegmented. Bears on its anterior and dorsal surface a pair of long jointed *feelers* or *antennæ* (important sense organs), a pair of large compound eyes, and three small dot-like eyes called *ocelli*. On the ventral side are the *mouth parts*, the organs which taste, grasp, and masticate the food. Note the short overhanging upper lip, beneath which is a pair of powerful *jaws* having a lateral or side position. Beneath the jaws are the *maxillae* and *under lip*. Note the two pairs of elongated and segmented *palps* (probably organs of taste).

5. *Thorax*, composed of *three somites*. Each somite bears a pair of legs on its ventral surface, and the two back somites each a pair of wings on the dorsal surface. Thus the organs

of locomotion are concentrated in the thorax. Find the sutures between the thoracic segments. The three segments may be difficult to distinguish at first, but each bears a pair of legs.

6. *Abdomen.* No appendages. At the hinder end is the *anus* and in the female the *sting*. The dorsal and ventral portions of the cuticula are composed each of a distinct plate in each somite.

7. *Spiracles:* the external openings of the respiratory system. They appear in a straight row of minute dots on each side of the abdomen and thorax, one dot being on each segment on each side. It is sometimes difficult to see them with a hand lens. In that case, remove a portion of the cuticula from the side of the body, and examine the inner surface with the microscope.

8. Draw the body × 5, and the face separately × 10.

9. Remove a leg from the hindmost somite and draw it × 5. The *coxa* is the segment articulating the leg with the body; the *trochanter* is a very small segment, the *femur* a long segment; the *tibia* or shank is also long; the *tarsus* or foot is composed of five small segments, the last one bearing two claws.

10. Remove a forward *wing*, and draw it × 5, showing venation.

Every opportunity should be taken of comparing animals of the same main group, and noting structural *differences*. For instance, with the wasp might be compared a *bee*, a large *beetle*, a *blue-bottle fly*, and a *grasshopper*, all easily procurable, and the following points might be noted.

Beetle.—The hard and thick forward wings are not used for flight, but are an additional protection for the back (they are called *elytra* or *wing-cases*); lift them and note how the wings proper are folded, transversely as well as longitudinally; the wings are wanting in some of the running beetles.

Blue-bottle Fly.—Note the hairy body; small antennæ with pinnate terminals; extend the *proboscis* and note *oral lobes* at lower end; the big thoracic somite bears the wings; the hind-

most thoracic somite bears the *balancers*, the morphological equivalents of the second pair of wings.

Grasshopper.—Pass a needle under the broad long upper lip and note the *mandible*; no separating constriction between thorax and abdomen; anterior wings are parchment-like and non-flying; proper wings folded up under them, like a fan.

But in drafting directions for comparative studies, draft them in such a way as to compel the observer to discover things for himself. For instance, instead of saying, " lift the elytra and note how the wings are folded transversely as well as longitudinally ", say, " lift the elytra and note the wings; extend a wing as if for flying, and then try to put it back as you found it; how does the insect probably get the wing back? observe the unextended second wing and describe it accurately ".

Further Work

Comparison is the very essence of all zoological study, whether morphology or physiology is under consideration. It is excellent practice for pupils to make diagrammatic cross-sections of animals studied, consistently colouring in the same way the various organs and tissues of each. A succession of diagrams of this kind, showing the gradation from lower to higher types of animals, always serves to impress the learner with clear notions of evolutionary development.

When dissection is undertaken, its main purpose should not be the study of morphological minutiæ but the study of comparative *function*. Let function be given a place *at least* equal to that of structure. And always bear in mind that the main purpose of all the work done is to trace developmental paths from lower to higher types, from the protozoan to the mammal. This idea of development the learner must get into his very bones.

Professor Thomson's, Professor Dakin's, and Miss Hymans's books (to mention only three) are so full of teaching

hints of all kinds, both as to selection of types and as to treatment in the laboratory, that it is unnecessary to give further details here. All the advice required for teaching zoology in Upper Forms is given in those books.

For laboratory work, it is best to concentrate on a few principal animal types, the animals selected being easily procurable, easily handled, and telling their own stories most readily. The following is a suitable list: Amœba (as an example of a less complex protozoan), Paramecium (a more complex protozoan), Hydra (a simple metazoan), then Planaria, Earthworm, Starfish, Snail, Crayfish, Bee, Amphioxus, Dog-fish, Frog, Pigeon, and Rabbit. One lesson each is enough for half of these, and the whole can be done in about twenty two-hour lessons. But of course there is practical work of other kinds to be done as well, e.g. the life histories of the butterfly, silkworm, moth, and frog, in addition to work suggested in the next chapters.

Laboratory Procedure. The Microscope

Always insist on the details of accepted laboratory procedure being rigorously followed—under-water dissection when possible, oblique fixing of pins, frequent changing of water, caution in cutting away tissues, keeping slightly on the stretch the parts under dissection, dissecting along and not across blood-vessels and nerves for cleaning, keeping all instruments clean and sharp, using clean droppers when handling small organisms, dropping cover-glasses on to a slide in such a way as to avoid air-bubbles. It is well to get out a list of all such rules of procedure, and make the pupils copy it on the first page of their note-books. Observance of such rules makes all the difference between success and failure in practical zoology.

Specific instruction in the proper use of the microscope is too rarely given, and the result is that only a small minority of pupils learn to get the best out of the instrument.

There should be one way and only one way of adjusting

the inst?ument, to be followed by all pupils. It is preferable to teach beginners to focus by racking back; racking down frequently leads to damage. Most beginners use two much light, with consequent loss of definition. The condenser is seldom wanted in school work, and of course is never necessary for lower powers, good enough light then being obtainable from the concave mirror. With more advanced pupils using higher powers, a condenser (with the plane mirror) is useful. A $\frac{1}{12}$-inch oil immersion should be kept in the teacher's cupboard, for the use of that occasional Sixth Form pupil who shows a flair for microscopy.

Train the pupil not to use a greater power than that really required by the object, never to close the left eye, never to use the fine adjustment for powers less than $\frac{1}{6}$ inch. The pupil's eye needs educating, and a beginner nearly always makes the mistake of using higher magnification than is necessary.

The beginner must also be taught that as much depends on correct illumination as on lenses. Let him take out the eye-piece and look at the back lens of the objective; it is probably filled with light. He should then close the iris down until about three-quarters of the lens is filled. This is about the best for a good definition.

Further, the pupils must learn that the plane of the focus of a lens is merely a geometrical plane. Since all objects viewed through a microscope have an appreciable thickness, not even the thinnest can be seen in its totality in a single plane of focus. Hence the pupil must be taught that, when viewing, he must vary the focus and so bring it into different planes.

The pupil should not only label all his sections consistently, but should note down the magnifications consistently. If an objective of $\frac{1}{4}$-inch focus forms its image at 10 inches, it gives at the distance a magnification of 40. If the magnification of the ocular is 10, the magnifying power will then be 40×10 or 400 (diameters). Most modern objectives are corrected to a tube length of either 6 to 8 inches, or 8 to 10 inches. The facts should be obtained from the makers, and the details posted up on the inside of the door of the case of each microscope.

Collections of Animals

London schools have a tremendous advantage in having at their doors the Zoological Gardens and the Natural History Museum. The special exhibits in the Central Hall and in the North Hall of the museum are highly instructive and should be seen by every zoology student. For instance, not far from the elephants is a case showing the damage caused by wood-wasps and their allies; the damage is remarkable. In the mimicry case is a recent addition showing mimicry in beetles. Then there is a number of skeletons of famous race-horses, and the visitor is able to compare the result of premature strain on the backbone of a horse raced as a two-year-old, with the normal backbone of the famous Eclipse who did not run until he was five years old. In short, there are to be seen all sorts of things full of interest to a naturalist; and a knowledge can be acquired that is an entirely different sort of knowledge from that obtained in laboratory courses, and even different from that obtainable from ordinary text-books. And of course the first-hand animal knowledge to be obtained at the Zoological Gardens is almost unlimited. The new Aquarium there is said to be the best in the world. A similar claim is also made for the new Reptile House.

More Useful Books

Borradaile's *Manual of Elementary Zoology*, Lulham's *Introduction to Zoology*, Bourne's *Introduction to the Comparative Anatomy of Animals*, Mr. Latter's *Elementary Zoology* (full of teaching suggestions), Lankester's *Zoology* (eight parts), Marshall and Hurst's *Practical Zoology* (an old friend still very useful)—all should be in the Teacher's Reference Library. Huxley's *Crayfish* and Marshall's *Frog*, written long ago, are still models of their kind.

CHAPTER XVIII
Human Physiology

To what Extent is the Subject Necessary?

If the school biological course includes the study of zoology, and if zoology has been properly taught, the essentials of physiology in the more general sense will have been mastered, and there will be little need to devote much attention to human physiology as such. If, on the other hand, zoology has not been included, and the pupil is introduced to the study of physiology exclusively from the point of view of the human body, serious difficulties are bound to arise. Any practical work attempted will, after all, be necessarily mainly work on the lower animals, and this, for the new purpose, can hardly be made zoologically systematic.

The courses of practical physiology I saw in schools thirty years ago were generally based on Halliburton's *Essentials of Chemical Physiology*. Naturally the book was much too difficult, the pupils' knowledge of chemistry usually being elementary; but, more than that, the book was inappropriate, for it touched only one corner of a very big subject, and it failed to provide the type of experimental facts required for establishing the principles underlying the so-called "theoretical" course which ran concurrently with the laboratory work. The "theory" dealt mainly with anatomy and histology, function being treated, when treated at all, in a very perfunctory sort of fashion. It is very doubtful, too, if such modern text-books on practical physiology as that typified by Sir E. S. Shafer's work is suitable for schools. The electrical apparatus now in common use for such physiological work is not available in schools, and the usual muscle-nerve preparations, and the nerve-conduction experiments, of the medical schools, hardly come within the range of work that ordinary school boys can best do.

It is interesting to compare Professor M. Foster's standard work on physiology, first published in the seventies, with the most recent edition of Professor Starling's work. It will be seen how anatomy tends to take a smaller and smaller place (it is, of course, provided elsewhere for the medical students), and physiology proper to occupy the premier position.

Assuming that essentials have already been taught through the medium of the zoology course, there are still certain additions which are necessary if pupils are to understand intelligently the working of their own bodily machine. A beginning might be made by reading Hill's *Living Machinery*, an excellent general book to rouse boys' interest in physiology. Then:

Topics for Special Consideration

1. THE HEART.—It is assumed that an elementary study of the beating frog-heart has been made.

(i) *The Heart-beat.*—Rate of beat in the human subject. Place a finger either on the heart-apex or on an artery (pulse). Do this with the subject recumbent, sitting up, standing up, and after a hard run. Note the differences in the rate and in the character of the beat.

(ii) *Elasticity of Arteries.*—At each beat, about $\frac{1}{4}$ pint of blood is forced suddenly into the aorta; there is a consequent arterial expansion and a pulse of pressure throughout the arterial system. The cycle of the heart. Place one finger over the carotid, and another over the artery at the wrist; the pulse at the former can be detected slightly before that at the latter. Evidently if we can measure this interval (as we can), and measure the distance from neck to wrist, we can estimate the *speed* of the wave. The pulse is not a *flow* of blood, but a *wave* of pressure. It runs much faster than the blood itself. The sphygmograph and its use.

(iii) *Blood-pressure.*—The medical practioner's sphygmometer (rubber cuff and mercury manometer) and the story it tells: when the applied pressure is high enough, the arteries are squeezed flat, and the pulsation of the heart ceases to go through to the lower part of the arm; how the pressure is recorded by the manometer.

(iv) *The Work of the Heart.*—Every second the heart discharges blood from its cavities with a force equal to the lifting of a weight of from 10 to 15 lb. Why does it not tire as other muscles tire? (This question may provoke an interesting discussion.)

(v) *Capillary Circulation.*—Microscopic observations of the circulation in the web of a frog's foot, or in a tadpole's tail.

2. THE LUNGS.—Respiratory movements; observations and records. Self-measurement of chest at deepest inspiration and expiration. Artificial respiration: practise on a recumbent subject.

3. THE SKIN.—Cutaneous sensation: determination of pain spots, warmth spots, cold spots, delicacy of different parts to touch.

4. THE EYE.—Co-ordinated movements of the eye; the optical system of the eye; mechanism of accommodation; normal and abnormal refraction of the eye; binocular vision. Theories of vision. (See p. 146.)

5. THE EAR.—Nothing very useful can be done unless the pupil has an elementary knowledge of sound. (See p. 143.)

6. BIO-CHEMISTRY.—We deal with this in the next section.

Then there are various things in physiology that all the world are interested in and keen to know something of, things which, although they cannot be included within the scope of formal science teaching, may receive informal attention for a few minutes on appropriate occasions during particular lessons. One such thing is the process of muscular and tissue repair after injury or operation. The late Sir James Paget's description

of the reparatory processes that took place in a rabbit's severed tendon, the separated pieces being nearly an inch apart, always makes a great impression on boys, especially the fact that, after the repairing process had gone on for ten days, it took a half-hundredweight to break again the newly connected tendon. (This test was made by removing the tendon from the dead body and slinging weights to it.) The repairs effected by nature are nearly always thorough.

Another interesting thing is nerve regeneration. This process though slow is even more wonderful than the other. If a nerve-trunk be cut, the nerve-fibres from the point of severance to the muscle or skin die along the whole length. But the other end, that in connexion with the brain, suddenly begins to grow (it may be after many years of quiescence!), and once more creeps along towards its proper goal, always ignoring alien tissues, until, threading through all obstacles, it reaches its goal and restores the broken function.—Such an interesting fact as this might certainly be introduced into a lesson on the nervous system, whether the lesson was one on zoological development or one in the separate department of human physiology.

There remains the difficult subject of bio-chemistry.

Bio-chemistry

Not the least important thing in teaching physiology is to tell pupils frankly that our knowledge of the subject is very far from being complete. Pupils should learn that the human body is a combined physical, chemical, and biological laboratory, the physical and chemical sections being fairly well understood, the biological scarcely at all. We reduce our physiology to physical and chemical processes, and these *as* physical and chemical processes we understand—more or less; but how these processes are initiated, how enzymes act, how hormones act, how vitamins act, how an animal wills, all these and a score of other things are simply baffling mysteries, and nobody has ever succeeded in devising experiments to explain them.

Until pupils have had a fairly good training in chemistry, including elementary organic chemistry, it is of little use for them to take up bio-chemistry. The subject is too difficult. The main source of difficulty is the extreme complexity of proteins; and all the phenomena which we term " life " are manifested by matter which is made up to a very large extent of proteins. All the other substances—starches, sugars, fats, salts, and the rest—are really of secondary importance, materials waiting to be used by the living structure, rather than fundamental parts of that structure itself.

Even well-prepared pupils will not be able to take up more than the outlines of bio-chemistry. The subject has become a big one.

The main difficulty underlying the investigation of proteins is their extreme liability to change. If a solution of protein be heated only a comparatively few degrees above the normal temperature of the body, irreversible processes of decomposition set in; or if the solution be made a little too acid or a little too alkaline, the original proteins are broken up and lost. Egg-white, which is composed chiefly of the protein egg-albumin, exemplifies this.

Great difficulties are encountered in obtaining most proteins in a condition of sufficient purity to ensure that their analysis will yield more than a rough quantitative significance. Their molecular structure is extremely intricate. But, by boiling with dilute acid, proteins may be broken down into simpler substances which for the most part belong to the group *amino-acids*, and, as these are closely concerned with food digestion, pupils should certainly know something about them.

It used to be thought that when once the digestive process had converted the food into soluble products, the molecules of which were small enough to permit of their diffusion through the mucous membrane of the alimentary canal into the blood, the whole object of digestion had been accomplished. And it is, of course, true that peptones are easily soluble and will diffuse, slowly, through membranes; they would seem, therefore, to answer the criterion of fully digested proteins. But

we now have reason to believe that the digestion of proteins does not stop at the peptone stage but continues until the free amino-acids are liberated.

This breaking down of the proteins of the food into their constituent amino-acids during digestion is a process which is not, strictly speaking, to be included among metabolic changes, for it occurs in the cavity of the alimentary canal (it is assumed that the pupils knew, from the earlier stages of their zoology course, that the alimentary canal is, morphologically, a mere tube external to the actual tissues of the body).* The term *metabolism* is reserved for such chemical changes as take place in the living cells themselves. During *digestion*, the proteins, and indeed the foodstuffs in general, are merely prepared for the metabolic changes which they have still to undergo. It is only when the amino-acids have been absorbed from the digestive tract that their metabolism begins.

A well-prepared Sixth Form boy should be able to understand this fundamental principle clearly. And he ought to be able to cover, in an elementary way, the following ground:

1. The general nature of digestion and metabolism.
2. Proteid digestion. Nitrogenous equilibrium. Proteid starvation.
3. Fats and their metabolism.
4. Digestion of carbohydrates. Diabetes and insulin.
5. The human machine. Fuel requirements and energy output.
6. Enzymes and ferments and their activities. Enzymes considered as catalysts.
7. Hormones as excitants. How the activities of the different parts of the body are probably correlated.

A short lesson on the accessory food substances, *vitamins*, should be included. No practical work is possible, too little being known about vitamins, but certain broad facts should be taught.

* For beginners, illustrate this by wrapping a closed bag round the hand. The hand is not "inside" the bag. Neither is the food in the alimentary canal "inside" the body. The alimentary canal is, morphologically, a mere continuation of the body-exterior.

We have no conception of the mode in which these bodies work. They do not correspond to our ordinary idea of enzymes or ferments. They are present in fresh food and tend to be destroyed by the processes of cooking and preserving. They are necessary for continued health, being essential for the carrying out of vital processes; but it is no longer supposed that they are chemically related to the amines, as the name vit-amins suggests. It is, however, certain that they are definite chemical substances, and they should not be referred to as if they were merely mysterious " principles ".

But practically nothing is known of their chemical composition. In foods they exist in incredibly small amounts, and yet they are known to be extraordinarily active and to be essential for health. Nobody has ever handled an isolated vitamin or seen one. They are tested by their effects on animal feeding.

The results of chemical research, combined with subsequent experiments on animal feeding, have shown that there are two groups of vitamins. Some are soluble in water and some in fats, these two substances being normal constituents of all living protoplasm. Of the fat solubles, the best known are " A ", " D ", and " E ". The two best known water solubles are " B " and " C ".

Fat-soluble vitamins are left behind in the 1 per cent of oil not turned into soap during the process of boiling with strong alkalies. We feel bound to infer that substances able to resist such drastic treatment must have a definite chemical constitution.

The following main facts about the respective vitamins may be taught:

Fat-soluble A.—Associated with the fat of milk, and with most animal fats, e.g. unrefined cod-liver oil. Necessary for the normal growth of young animals, also to prevent rickets, a disease in which calcification of bones and teeth is deficient. In its absence there is a susceptibility to eye-ulceration, to colds, to pneumonia, and to tuberculosis. Vitamin A is present in butter, milk, cheese, beef and mutton fat, eggs, water-cress, maize, carrots, bananas, and tomatoes.

Water-soluble B.—An anti-neuritic vitamin, found in the outer layers of rice-grains and in many other tissues, both plant and animal; also in yeast. Beri-beri is a disease amongst Eastern peoples who eat white rice. In the absence of vitamin B there is a marked susceptibility to nerve trouble (neuritis, degeneration of the nerve-tracts). Vitamin B is present in the husks of cereals; hence it is present in oatmeal and in brown bread; also in white bread made with yeast.

Water-soluble C.—The anti-scorbutic vitamin. It is abundant in the tomato and in the *Cochlearia officinalis* (scurvy grass), and it is present in oranges, lemons, grape-fruit, water-cress, lettuce, &c.

Fat-soluble D.—The anti-rachitic vitamin. It often accompanies A, and thus is found in animal fats, butter, milk, fish, oils, &c. Exposure to light compensates for a reduced amount of this vitamin. Rays of short wave-length seem to act by producing a synthesis of the lacking substance. The substance called ergosterol is a powerful absorbent of ultra-violet rays, and by adding irradiated ergosterol to such foods as margarine, the nutritive quality is greatly improved. Until recently, cod-liver oil was supposed to be the best available source of vitamin D.*

Fat-soluble E is present in wheat-oil. It is essential to fertility, but we know little about it yet.

It seems clear that the vitamin content of even the poorest diet may be restored abundantly by the addition of cod-liver oil or fresh milk and butter, a yeast extract, and orange juice.

Actinotherapy

Reference was made to light-exposure as a possible compensation factor for reduced vitamin D. In view of the rapid development of actinotheraphy, one or two lessons on the subject are advisable: e.g. the physical basis of light therapy, natural and artificial sources of ultra-violet radiation, the bio-

* In *Nature* for March 3, 1928, there is an interesting letter dealing with birds' methods of feeding their young with feathers, with the apparent object of supplying anti-rachitic vitamin D.

logical action of ultra-violet rays, the use of ultra-violet rays in the home, ultra-violet lamps, dangers and precautions. The supplement to *Nature*, 21st April, 1928, contains several useful articles on the theory and practice of the subject.

CHAPTER XIX

Embryology

Why Embryology should be Taught

One reason, perhaps the main reason, for including in a school biology course at least a few lessons on embryology is that pupils may be able later to understand the inner meaning of much of the evidence adduced on behalf of the hypotheses of evolution and heredity. In Darwin's opinion, the facts of embryology afforded the most conclusive of all evidence in favour of the hypothesis of evolution. The resemblance between the embryos of various animals is much closer than the resemblance between the adults. The fact that the embryos of such vertebrates as birds, and snakes are almost indistinguishable from one another at the earliest stages of their development, and the fact of similarity, in embryos, of homologous parts which later on become differentiated, point back to common ancestors. A strong confirmation is afforded by the survival of vestigial organs. It follows that the hypothesis of evolution can hardly be made intelligible to pupils unless they have some knowledge of at least the bare fundamentals of embryology.

The pupil must understand that embryology has for its subject-matter the growth of animals from the time they first appear as germs in the bodies of their parents until they reach the adult condition and are able to produce similar germs themselves. It thus includes the study of a complete life-cycle. In practice, of course, the study of the adult form

precedes the study of all other stages of the life-history. It is, however, extremely difficult to obtain, with any completeness, knowledge of the whole course of any given life-history. Such knowledge as we have is usually the result of inferences from comparisons of many individuals of various ages. In the case of the vast majority of animals, only a few scraps of life-history are known, and the piecing together of these is a formidable task.

The pupil must also understand that " birth " is nothing more than a passing phase in the life of a new organism. True there are then certain new phenomena. For instance, when a child is born, the nerve centres which regulate the complex apparatus of breathing start into instant and effective operation. When the mother's breast is presented to the child, the child immediately starts sucking, the nerve centres which regulate this intricate series of actions beginning to work as if they had already served a long apprenticeship. A young duck swims with orderly strokes as soon as it leaves the shell. We cannot explain how such marvellous evolutionary results have been reached.

The provision of suitable practical work for pupils is a serious difficulty, and yet without practical work the subject can neither be presented with much reality nor be appreciated at its proper value. Much will depend on the material available, and concerning that the nearest university professor of zoology may always be consulted.

The Basic Facts to be Taught

The main facts to be impressed on the learner's mind are:

1. That an egg-cell after fertilization enters on a series of changes collectively called *development* and that embryology is concerned with the study of these changes.

2. That the egg after it has begun to develop is called the *embryo*, a term (or *fœtus* in mammalian embryology) which always applies to the unborn young.

3. That the embryo may complete its development either within the egg-shell or egg-membrane, or within the parent body, though it may become free at some earlier stage as a *larva*. In the former case the young at birth very closely resembles its parent; in the latter it is very dissimilar, and the larva has to undergo a metamorphosis before it reaches the adult state.

4. That the developing embryo exhibits a progressively complex structure, the various steps in the production of which occur in an orderly sequence.

5. That the first stages in the development are more or less similar in all animals, and that thereafter the development of animals of different groups diverges.

6. That cell-multiplication and the subsequent growth of the daughter cells are the general and fundamental processes conditioning differentiation.

7. That the first stages consist of the repeated division of the fertilized egg by mitosis, until a large number of cells are produced.

8. That as the egg-segmentation proceeds, localized growths resulting in enlargements and constrictions occur; that cell-aggregates gradually form cords, sheets, and masses; that *delamination* occurs, i.e. the splitting of sheets into separate layers; that in these sheets *folds* resulting in evaginations and invaginations are produced, i.e. sheets of cells are folded outwards and inwards.

9. That these folds, due to unequal rapidity of growth, are the chief factor in moulding the organs and thus in giving the general form to the embryo.

10. That the differentiation of the cells and the parts of the embryo continues until the adult morphology is completed.

Practical Work

The *blastula* and *gastrula* stages of segmentation should be clearly recognized. The method of development of those two forms may be easily shown by making rough models from

strips and small sheets of clay or plasticine with the surface roughly marked to indicate cells. Only a little skill with the fingers is required to illustrate in this way the earlier stages of embryonic development. Blackboard sketches are not enough; some learners simply cannot visualize three-dimensional bodies from such sketches.

It is probably best to begin practical work by examining hens' eggs taken from an incubator, and studying the contained *chick* embryos. The embryo may be studied whole, and most of the main structures easily identified during the first two or three days of incubation. Eggs may be opened every 6 or 8 hours during the first 4 or 5 days of incubation. The best stages for early examination are those at the end of the 24th, 33rd, 48th, and 72nd hours. The gradual formation of the several organs may be easily observed. The eggs should be opened in normal saline solution at 40° C. It is a simple matter to cut round, with scissors, the germinal disc, to float the embryo off the yolk, to remove the vitelline membrane, and then to float the embryo, dorsal side up, on to a glass slide. It should be remembered that the egg is normally laid in the gastrula stage. After the laying, the egg cools, and development ceases until incubation is begun.

Frogs' eggs are also suitable material for study. The eggs are relatively large because they contain a considerable quantity of yolk. The jelly secreted by the oviducts of the frog at the time of laying causes the eggs to adhere in masses, and this jelly must be removed before an attempt is made to study the egg or embryo. The eggs may be studied in cleavage under the low power or with a hand lens; sections of the blastula may be made and sketched; also sections of the gastrula; also, at successive later stages, sections of the embryo. The time between laying and hatching is 1 to 3 weeks, according to the species and to the temperature of the water.

The eggs of the star-fish also afford excellent material for the general study of typical early embryonic development.

The process of embryonic development as a whole cannot clearly be shown in the case of any single animal. Different

animals must be selected according to the particular purpose in hand. The tadpole (the larva of the frog), for instance, may be utilized for a simple study of the later stages. Tadpoles may be taken as soon as hatched, suitably fed, their further development watched and described, and the times when changes take place noted, especially the appearance of the hind limbs, then of the fore limbs, then of the rapid metamorphosis into a frog.

It is important for the pupil to be able to *visualize* the changes in the developing embryo. He should first examine the whole embryo at as many different stages of its development as possible; then perhaps dissections; then the whole embryo in serial sections. The complete picture of the development from egg to adult may thus be gradually visualized. The older embryologists had to be satisfied with the knowledge gained from the study of the entire embryo and of minute dissections. Now the egg or embryo is cut into a number of exceedingly thin slices, arranged in order on glass slides, and examined under the microscope. With a little practice, the necessary visualization may be satisfactorily effected.

Mitosis

The teacher who attempts practical work in mitosis must be a skilled microscopist. If he is not, he should use prepared slides instead. After all, many of the phenomena of mitosis are at least as much a matter of inference as of observation.

The germ-cells of *ascaris* are perhaps the best material for studying the different stages of mitosis. The eggs are of fair size, division is fairly rapid, and the chromosomes are large and few in number. Under a low power, the cavity of the oviduct may be seen to be filled with eggs. Longitudinal sections of the oviduct may be made in the region where the eggs are developing, and it is possible that some of the various stages of mitosis may be found when the eggs are then examined under a high power. It may not be easy to find any particular stage, especially as some of the eggs will probably not be cut

in the right plane to show the mitotic process to advantage. Successful work demands a skilful hand.

The reproductive organs of several of the lower animals at the time of sexual activity also provide suitable material, as the cells are dividing rapidly to produce the new cells. The testis of the crayfish is often used. The root-tips of plants grow very rapidly in some cases and are therefore favourable places for finding the stages of mitosis. Make longitudinal sections through the tip. The growing region where the dividing cells are situated are a little back from the root-cap.

Whether or not any practical work is done, the phenomenon of mitosis must be clearly understood, less perhaps for a clear general understanding of embryology as such than for a clear realization of the nature of chromosomes and the part they play in heredity. See the next chapter.

Animals and Plants

The pupil should note the essential distinction between the embryology of animals and the embryology of plants. In the higher animals the embryology is carried out once for all; for instance, the limbs are laid down and, normally, no further members are formed. But in plants the formation of new members is continued throughout the whole of active existence.

The "Recapitulation" Theory

The pupil must also understand what is meant by "recapitulation" in development: any particular plant or animal seems to begin to develop in much the same way as the embryos of all the plants or animals below it in the evolutionary scheme of classification. The fundamental law of biogenesis is that the individual in its development recapitulates the development of the race. If such a law were substantiated, it would bind up all the innumerable phenomena of development into one coherent scheme. But it has now been demonstrated that this law of parallelism is strictly limited, though biologists agree that any

given life-history contains ancestral elements. The developing chick is, at a very early stage, demonstrably a vertebrate, and does not recapitulate the organization of a polyp or a worm or a mollusc. The recapitulation is never that of the *whole* organization of a lower animal, but only that of particular parts. Any given life-history exhibits many features which in no way reflect the characters of ancestors. And yet if evolution be a fact, it would not be unreasonable to expect that the recapitulation would be complete, and it is admittedly true that the *early* stages of embryonic development seem to be extraordinarily alike in all animals. If in the later stages there is a recapitulation, many of the steps must be rapidly hurried over and practically omitted.

Common to all embryos is the origin in a single fertilized cell, the division and subdivision of this cell, the formation of a mass of cells, and then the folding up of this mass. But with this folding, the mass begins to mould itself in a specific way. What is the origin of this differentiation? Presumably it is traceable to the parents, for ultimately the embryo becomes a copy of the parents, not a perfect copy it is true, but a recognizable copy and yet a copy with differences. This fact is the natural introduction to the study of heredity.

Human Embryology

It is not necessary to touch upon human embryology, except perhaps in a very incidental kind of way. In taking up heredity and evolution subsequently, the teacher may safely presume *inferential* knowledge. Sixth Form boys and girls in their second year are generally quite sensible over matters of this kind.

Material and Books

There are many series of prepared embryological slides that may be purchased. An excellent series of the embryo chick, seven in number, may be obtained from Messrs. Watson of

Holborn. Messrs. Flatters and Garnett also have a very useful series of preparations, the later stages being mounted in glass jars. In Lull's *Organic Evolution* there are figures of a comparative series of embryos, at four different stages, of a fish, salamander, tortoise, chick, pig, calf, rabbit, man. See also Lull's *Evolution of Man* (fig. 23). For methods of collecting embryos, killing, fixing, preserving material for microscopic work, mounting entire embryos, embedding and section cutting, see Shumway's *Vertebrate Embryology*. Several of the American books give particularly useful hints on practical work, but it is doubtful if, even now, there are better instructions for practical work than those given in a book written nearly fifty years ago by Professor Michael Foster and Professor Francis Balfour. See pp. 423–60 of the 1893 edition. The details for obtaining and studying chick embryos and for cutting sections are clear enough for any novice to follow. Another suggestive little book is Mr. de Beer's *Experimental Embryology*.

CHAPTER XX

Heredity

The Basic Facts for the Pupil

Practical work on the subject-matter of this chapter and the next is almost out of the question, and all facts must be supplied second hand. From the point of view of science *training* there is much to be said for making the respective courses of instruction as short as possible. As, however, so comparatively few laymen seem to have clear notions of the actual evidence on which the theories of heredity and evolution are built, the least that should be done in a Sixth Form is to present the evidence, clearly and logically, in some half-dozen lessons on each subject, and to show to what extent the generally accepted inferences from the facts are justified.

So far as heredity is concerned, lead the pupils to understand, first, what the term implies—that living organisms can produce their like, the resemblance, though never absolutely perfect, extending to the most minute details of structure and function; secondly, that any theory of heredity, to be acceptable, must account for all the main facts of the general likeness of parent and offspring. In particular:

1. *Variations* occur in the offspring, i.e. characters that are not exhibited in the same degree by the parent.

2. Specific *similarities* occur in the offspring, i.e. characters that occur in one or both parents.

3. Characters may occur in the offspring that do not occur in either parent but that did occur in a grandparent or in some remoter progenitor.

4. Characters acquired by a parent in the course of his or her life, as the result of apparent interaction with the environment, *seem in some cases* to reappear in any offspring subsequently born. (This has given rise to great controversy.)

Further basic facts for the pupil to understand are: (1) the difference between (*a*) *continuous*, and (*b*) *discontinuous* or *saltatory* variations; and (2) the difference between (*a*) *innate* or *germinal* variations (whether continuous or discontinuous) and (*b*) *acquired* characters. The innate or germinal variations is that important remainder left after there have been subtracted from the whole not only all the differences of age and sex but also all the acquired characters; they are those which are inherent in the individual, and are largely independent of the manner of life.—These various terms are the current coin of all discussions on heredity and must be fully grasped.

Hypotheses of Heredity

Most of the theories that have been put forward to account for all the facts are ultimately based on a relatively small number of actually observed processes of cell-division—the processes of maturation, mitosis, and segmentation—and the

inferential evidence derived from these processes. For at least two centuries, the sperm-fertilized ovum has been looked upon as containing in *some* way the physical basis of the new organism.

Some of the hypotheses have a statistical basis; others are unrelated to statistical experiments of any kind. Nearly all scientific hypotheses are, of course, based on a certain number of observed facts, and to that extent are statistical. Even Avogadro's hypothesis originated in the few experimental facts constituting the law of Gay-Lussac. Any hypothesis whatever should be based on facts of observation and experiment, and the descriptive scheme put forward should enable us (1) to trace out in detail the processes which lead to the facts observed; and (2) to use it as an instrument for predicting occurrences not yet observed. The pupils should be encouraged to try to apply these tests to the various hypotheses of heredity, and to ask themselves if they feel more satisfied with one particular hypothesis than with the others, and, if so, why.

The principal hypotheses may be thus tabulated, and the pupil be instructed to memorize them:

1. Non-statistical hypotheses:
   (1) The Preformationist hypothesis.
   (2) The Epigenesis hypothesis of Wolff and others.
   (3) Lamarck's hypothesis of transmission of acquired characters.
   (4) Darwin's Pangenesis hypothesis.
   (5) Weismann's Germinal Continuity hypothesis.
2. Statistical hypotheses:
   (1) Galton's and Karl Pearson's hypotheses.
   (2) Mendel's hypothesis.

We append a brief summary of such facts as should be taught.

The Preformationist Hypothesis.—This was the favourite hypothesis during the seventeenth, eighteenth, and earlier part of the nineteenth centuries. The germ of one of the two parents was supposed to contain within itself a complete miniature model of the parent; it had only to be unfolded or evolved or increased in size in order to become the new animal. It was taught that within this miniature was a second, within

the second a third, and so on for all future generations. Supporters of this juggler's nest of boxes asserted that nothing new was ever generated, that everything pre-existed. The absurd hypothesis held sway until Wolff's demonstration of the gradual development, in the case of the chick, of the apparently simple into the manifestly complex. Wolff showed conclusively that the development was epigenetic, taking the form of a true series of transformations.

The Epigenesis Hypothesis.—This hypothesis assumes that the evolution of an animal consists of a gradual increase of complexity from what at first appears to be comparatively simple, and that in this way something essentially new really does arise. But just as the preformationists could not account for the origin of their miniatures, so Wolff was unable to explain satisfactorily the demonstrated fact that the end-result of epigenetic development was an individual similar to its parents.

Lamarck's Hypothesis.—Essentially, Lamarck's hypothesis was that " acquired " modifications are being continually produced and perfected by every organism during its life, and that they are at least partially transmitted to its offspring, so that each generation will be rather better adapted to its surroundings than its predecessor. In this way, the great length of the neck of the giraffe would be explained by the continual striving through many generations to reach higher limbs in the trees; and the limbless condition of snakes would be explained by the gradual loss of limbs through disuse.

Darwin's Pangenesis Hypothesis.—In the pangenesis hypothesis, the germinal cells are supposed to contain samples contributed by all parts of the body, and in the embryo the samples give rise to parts similar to those from which the samples came. Darwin's hypothesis was an hypothesis of this kind. Darwin assumed that every cell of the body, not too highly differentiated, throws off at each stage of its development characteristic *gemmules*, or small particles, which later multiply by division and give rise to cells like those from which they originated. These gemmules, which are conveyed in the blood, become specially concentrated in the germ-cells of both sexes,

or in buds. In the development of the embryo, these gemmules unite with others like themselves and, being aggregated in the germ-cells, they invest the germ-cells with the power of developing into a complete organism; but during the development of the embryo, some of the gemmules may remain latent through several generations before they become active.—This ingenious hypothesis certainly accounts for the known facts of heredity, and it affords a simple explanation of the transmission of characters which may remain latent for several generations. But though the gemmules may be *conceived*, they cannot be *perceived*. There is just a slight possibility of the hypothesis being in harmony with facts not yet known, but we cannot say more than this. Gemmules *may* have an objective existence. We do not know.

Weismann's Germinal Continuity Hypothesis.—This is an hypothesis of both heredity and racial evolution. It is based on the notion that the continuity of characters in heredity is to be thought of as the result of a continuity of material between parent and offspring, that continuity holding good through an indefinite number of generations. The essence of the hypothesis is *germinal continuity*. Weismann taught that the germ-cells are to be regarded merely as parts of an unbroken line of germ-plasm, the bearer of the heritable qualities; that in certain circumstances this germ-plasm frothed up and produced a great excrescence, the somatoplasm, the body of the next generation, and in that somatoplasm the germ-plasm continued its existence; that the germ-plasm thus passed on from generation to generation, but that the great excrescence thrown off from time to time, the animal " body " as we commonly call it, in due course died. Weismann postulated that an individual is like his parents not because he is produced by them but because both parent and offspring are produced from the same stock of germ-plasm.

In the division of the primitive germ-cells, the nuclear substance, the *chromatin* (so-called because it absorbs stain) becomes arranged in the form of a definite number of rods or *chromosomes*.—Points for explanation: the general phenomenon

of mitosis: the cell and its cytoplasm, the nucleus and its contained chromatin, the centrosomes, the formation of the chromosomes or idants (a definite number in each species, said to be 48 in man), the halving of the chromosomes before conjugation (i.e. the process of maturation), and the assumed parental contributions of the chromosomes. The pupil is now in a position to understand the nature and inner significance of the germ-plasm hypothesis: it is assumed that each chromosome contains germ-plasm derived from the ancestors of both parents; that therefore the chromosomes contain an accumulation of material derived from earlier ancestors on both sides; that each chromosome is definitely organized into a number of *ids*, each id seeming to contain within itself, in some way, all the generic, specific, and individual characters of a new organism, in short, a complete inheritance; that the ids are similar but not exactly the same, and that the animal which develops is a compromise between the various ids; that each id is itself an organization with individual constituents called *determinants*; that each determinant is concerned with the formation of some special organ in the embryo; that each determinant is itself usually composed of a group of *biophors*, the minutest vital units but each an integrate of numerous chemical molecules. Thus the *id* represents the complete individual, the *determinants* its different parts and groups of cells, the *biophors* the " characters ". It is argued that the biophors must actually exist, since every phenomenon of life must be connected with a material unit of some kind.

Weismann's hypothesis is extraordinarily ingenious, and adequately covers all the facts. But it is based upon inferences drawn from the all too scanty observations of chromosome division into ids, and it is very doubtful if the assumption of the continued subdivision into determinants and biophors is justified.

Had Darwin lived, he would probably have abandoned his gemmules and have concentrated on the phenomena of nuclear division. The great majority of present-day investigators are definitely of opinion that the nucleus is the seat of the hereditary

Francis Galton, who was followed up by *Karl Pearson*, dealt with such factors as stature, colour of the eyes, disease, the artistic faculty. The characters in sweet peas and in moths were also investigated. Galton's ascertainment of the facts of correlation between the characters of the child and that of its more remote ancestors affords some confirmation of Weismann's hypothesis of the continuity of the germ-plasm, so far as this hypothesis can be said to include an accurate description of known facts. Galton's law of ancestral inheritance has a foundation which is firm thus far—that it is based upon observations which have subsequently been systematized: the two parents between them constitute *on the average* one-half of the child's inherited faculty; each contributes $\frac{1}{4}$. The 4 grandparents amongst them also contribute $\frac{1}{4}$, or each $\frac{1}{16}$. The sum of $\frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \ldots$ is equal to 1, as the law would lead us to expect. This law is purely *statistical*, dealing only with large averages. It is merely a summarized record of actual observations. Its hypothetical element is small.

Mendel undertook a very different class of investigations relating to the laws of inheritance in hybrid varieties. He hit upon the device of selecting one at a time out of the many thousands of characteristics of an individual, and finding out how that one is transmitted through several generations. He experimented in 1866, chiefly on varieties of peas. The records of his work were brought to light in 1900, and Mr. Bateson drew attention to them.

Mendel had taken for his problem the question as to the exact manner in which the definite and true-breeding varieties within a species are related the one to the other. He concentrated his attention not upon the individual as a unit but upon the mode of inheritance of pairs of sharply contrasted characters. The method he adopted was that of hybridization, and he kept accurate pedigree records, showing the ancestry and the characterization of each individual. He counted the number of individuals in each generation, and the numbers of dissimilar kinds, and was thus able to give an exact mathematical statement of his results. In this way he reduced the

phenomena of inheritance to a measurable basis. Out of his experimentation emerged clearly the verifiable fact that when one or more pairs of alternative characters are involved in a breeding experiment, there is in the second hybrid generation an orderly reappearance of these characters in definite numerical proportions.

When the records of Mendel's work were brought to light in 1900, it was recognized that in them was confirmation and extension of the essentials of Weismann's hypothesis, but the work of recent years has led to a modification of Mendel's laws. The revised Mendelian hypothesis is like the Weismann hypothesis in this fundamental respect: it implies that the germ-plasm of organisms is not an invariable whole but an organization of units or factors which can be dissociated and recombined in various ways. Mendel's units are called *genes.* Breeding experiments seem to be generally confirmatory of Mendelian principles.

Further points for class-room explanation: dominants and recessives; the law of inheritance; hypothesis of gametic segregation. Mendel's experiments with peas might be repeated in the school garden, the annual results being recorded for consideration by boys in successive Sixth Forms.

Main Principles now Generally Recognized

There is a consensus of opinion that the secret of heredity is to be found in the fertilized germ-cell. The pupils must therefore know:

1. That although the individuals of a generation die, life is transmitted to the next generation through the function of reproduction.

2. That, in the higher forms of life, this consists in the union of the gametes, egg and sperm, to form the zygote, the new individual of the next generation, embodying all the possibilities of individual development and of racial perpetuation.

3. That although each of the two parents contribute but

a single cell so minute as to be far beyond the limits of the unaided eye, yet these gametes are the only material link between the generations, and across this extraordinarily narrow bridge everything organic which any generation can receive from its predecessor must pass.

4. That the zygote exhibits none of those details of structure and function which, when the individual has assumed its definitive form, will enable the observer to describe and to classify it, yet in this fertilized egg there must surely be *something* that predetermines much of the individual's future morphological, physiological, and psychological limitations.

The pupil must also know that although the phenomenon of metosis is perplexing and still full of doubt, and although we have very little exact knowledge of the chemical nature of chromatin, yet it has been definitely established:

1. That chromatin is intimately related to the activities of the cell as a whole.

2. That it has a definite architecture and disposition within the nucleus.

3. That during cell-division it assumes a condensed appearance, and displays its organization as a number of units, the chromosomes.

4. That the number, size, form, and behaviour of the chromosomes are constant in a species, and characteristic of that species.

5. That even when the chromatin is thus condensed in the form of chromosomes, it still retains its organic contact with the non-chromatic part of the cell, of which it is but a part though an essential part.

6. That no development is possible at all in the absence of at least one haploid set of chromosomes.

7. That as the result of countless experiments, the chromosomes are regarded as the only identifiable cell-organs which can satisfy the demands made upon the germ-plasm, and that in their observed behaviour are realized the precise condition of hereditary transmission.

8. That although Weismann's ids, determinants, and biophors are purely hypothetical, Weismann was undoubtedly right in locating his units in the chromosomes; and that it is now fairly definitely established that each chromosome bears a certain number—presumably a vast number—of the hereditary factors or *genes* (as the Mendelian units are called), that each gene has its own particular place within a particular chromosome, and that there is an exact parallelism between the chromosome-containing genes and the distribution of the hereditary characters.

9. That the chromosomes in the *immature* gamete are present in pairs, and that one member of each pair has been received from each parental organism.

10. That in the *ripe* gamete, only one member of each pair of homologous chromosomes is present, and that the sorting of the chromosomes during the maturation of the gamete is *at random.* Hence,

(i) since there are equal chromosome contributions from each parent,
(ii) since there is a random assortment at maturation,
(iii) since there is a chance recombination in fertilization,
(iv) since there is a possibility of an inner reorganization of each chromosome through its most intimate association with another of identical structure but different content,

it must follow that an almost infinite range of new combinations of character is provided, and thus the chromosome mechanism can supply the variations upon which the forces of selection can operate.

It is advisable in teaching to emphasize the fact that much of what is described in the process of mitosis is quite invisible even under the highest powers of the microscope, owing to the fact that almost all the parts of the living cell are really quite transparent; and that it is a little dangerous to assume that the phenomena seen in a stained (and, therefore, presumably dead) cell represent a true picture of the living cell: it

is just possible that the appearances are merely incidental to the death of the cell.

Thoughtful pupils are generally sceptical about the possible existence, in such a microscopic thing as the zygote, of the necessary millions upon millions of units representing all the different parts of the future body. They recognize the necessity of assuming within the zygote a very complex machinery of *some* kind, but they want something that can be visualized, and not merely conceived. They are less sceptical about the Mendelian gene than about Weismann's biophors, but they tend to pause when they think of the still necessary vast number of genes to correspond to all the unit characters that can be observed in experimental breeding. There is, of course, a certain amount of evidence that genes actually exist and are arranged in pairs, and that the pairs are grouped. The safer plan is, however, to tell the pupils that the genes are purely hypothetical, but that the results of experimental breeding are such as to be readily explained if it be assumed that genes do exist, and are grouped in a particular way. Even the remarkable results of the breeding experiments with *Drosophila melanogaster* throw no certain inner light on the machinery concealed within the chromosome, and yet Morgan and his American coadjutors can now produce, so it is said, almost any kind of fly to order!

Occasionally a boy will notice that the phenomena of mitosis, especially as displayed in some of the conventional diagrams, present a symmetry which is strikingly analogous to that of the phenomena of a bipolar electric field; and, if he happens to have a liking for chemistry, he may be inclined to look upon a dividing cell as an electrolytic phenomenon, full of wandering ions. Even if mitosis can be explained as the result of a conflict between surface tension and its opposing forces (as some biologists suggest), this is carrying the explanation only one stage farther back. Possibly we may *account* for the phenomena if we assume that the same forces are at work as in phenomena of grosser nature, but the assumption is not justified. To leave upon the pupil's mind the impression

that the living cell is exclusively a thing of physics and chemistry is not justifiable. It is more than that, it is dishonest, because *we do not know*. Even if all the factors of heredity are ultimately traced to chromosome units of *some* kind, we shall only be able to explain the mere mechanism of heredity. The essential phenomena of life will still remain unexplained.

Not the least important thing in the subject of heredity for a boy to understand is that the great controversial question in all hypotheses of heredity is the inheritance of acquired characters. An acquired character is a structural change in the body, of a kind which involves some change from the normal structure of the species to which the individual belongs. It is acquired and remains permanent during the life-time of the individual, and can be shown to be traceable to a change of environment such as climate, or to functional use or disuse such as is involved in specialized habits. From the point of view of any hypothesis of germ-plasm, the question whether a somatic modification of this kind is heritable or not is equivalent to the question whether such modification is accompanied by a specific change in the germ-cells, such that the offspring will inherit the modification which the parent acquired. When the evidence as to the inheritance of acquired characters has been presented *pro* and *con*, the verdict is *not proven*, and this impression should be left on the pupil's mind.

CHAPTER XXI

Evolution

The Great Range of the Subject

In the narrower sense, evolution and heredity are very closely allied subjects, but the term evolution was used by Lyell to denote the moulding of the earth by natural forces. Darwin did not employ the term at all in his book *The Origin of Species*. In its broader sense, we may think of evolution as the ascent of man from the lower animals, the ascent of the lower animals from some primordial form of life; and perhaps we may cross the bridge to non-living matter, and consider the origin of the earth and even of the solar system. It is well at the outset to impress upon the pupil that, in considering the process of evolution, we are still held up by two unsolved problems: (1) the origin of life, (2) the origin of species. Some account of the rival theories of the origin of life should be included in any biological course. In the study of evolution in the ordinary sense, the central features are the origin of species and the Darwinian theory that the almost inexhaustible variety of living plants and animals have arisen by descent from a few stocks, or perhaps from only one stock, of simple ancestors.

So far as difficulty of understanding is concerned, the subject is well within the range of Sixth Form work. Of necessity it has to be presented more or less in lecture form. Practical work is hardly possible unless, perhaps, the teacher is a keen Mendelian. The greatest teaching difficulty is to get at basic facts—facts which are acceptable generally, and from which sound deductions may be drawn. The literature bearing on the subject has become so extensive, and in many of even the best books facts and theories are so inextricably intermingled, that the unravelling is a formidable task. From the

teaching point of view, the following is probably the most satisfactory sequence of topics. It is reasonably logical, and an intelligent pupil ought not only to be able to thread together the facts and the arguments deduced therefrom but to be convinced of the probability of the truth of the main thesis, even though we are still really ignorant of the actual nature of the evolutionary process at work.

A Suggested Sequence of Topics

1. ORGANIC EVOLUTION ACCEPTED AS A FACT.—Organic evolution is now regarded by most educated people as a definitely established fact. The old idea of the special creation of different species has been abandoned. Bacon, Descartes, Leibniz, and Spinoza all held the general idea of evolution. Buffon was the first naturalist who expressed clearly the idea that the unity of plan in the structure of animals may be due to community of origin. Linnæus hesitated. Cuvier opposed. Lamarck opposed at first but changed his mind and became a thorough-going evolutionist. Darwin brought forward evidence which convinced the majority of intelligent people.

2. SPECIES AND THEIR ORIGIN.—Nobody asserts that cats are the ancestors of dogs or dogs of cats: the differences between them are too great. Dogs have 42 teeth, cats only 30, and there are all sorts of other differences, just as fundamental. But it is generally believed that dogs and cats probably had a common, though very remote, ancestor. And it is universally believed that all varieties of the domestic dog had a common ancestor; despite differences of appearance, the similarities of structure are very close. But when we consider dogs, wolves, and jackals, despite the fact that they closely resemble one another in some ways (they all have 42 teeth, for instance), the differences are too marked for all to be included in one class. They form different *species*; the differences between them are *specific*. But we do group them together under the one *genus*, " canis ".

One variety of dog is bred from another, one variety of pigeon from another; the small differences of a selected kind between one generation and the next are accumulated. But no one has ever succeeded in breeding a new *species* from an existing species; the difference is too great. It is believed that it could be done in time, but it would probably mean tens of thousands of generations. And we are not *quite* sure that it could be done at all.

3. THE EVIDENCE FOR EVOLUTION.—Since evolution is a process which requires for even its partial accomplishment many millions of years, *direct* evidence is unobtainable. The evidence is indirect. The available facts may be classified thus:

(i) *Facts from Comparative Anatomy.*—Morphological comparisons are made of existing allied species. The known facts have now become so numerous that their cumulative effect is almost overwhelmingly convincing.

(ii) *Facts from Embryology.*—We have already referred to the recapitulation doctrine. How far can it be said that the embryo climbs up its own genealogical tree? The inheritance of a living creature is possibly some sort of condensation of ancestral initiatives which compel the developing embryo to retrace, to some extent at least, the path taken by the embryos of its ancestors.

(iii) *Facts from Palæontology.*—A comparison of fossil species is made with each other, and with living specimens. The earlier records are obliterated, but we have excellent records of the vertebrates, and it is clear that mammals originated from reptiles of the later Palæozoic era. In proportion to the completeness of the palæontological records, the character of the testimony to the truth of the theory of evolution seems to be more and more unequivocal.—We return to this subject in the next chapter.

(iv) *Geographical Distribution.* — Darwin gathered three classes of facts during his five years' voyage in the *Beagle*: (1) the manner in which closely allied species replace species, in going southward; (2) the close affinity of the species inhabiting the islands near South America to those proper to the continent; (3) the relations of certain living species to extinct species. — A few examples of these should be given. As evidence, their cumulative effect is impressive.

(v) *Vestigial Organs.*—The more common should be mentioned.

4. Principles established from the Evidence.—Certain principles seem to hold good for all the main groups of animals in which checking is possible, and not only for the vertebrates:

(i) When a higher type evolves from a lower, this does not, as a rule, lead to the total disappearance of the lower. But although representatives of the lower usually survive, the total number of species is reduced.

(ii) As each new type comes into being, we find in general: (*a*) there is a considerable period during which the new type is not fully perfected; (*b*) comparatively suddenly, the new type ousts the old from its position of dominance. Examples: the early mammals which existed during the age of reptiles rose suddenly at the close of the secondary period; in mesozoic times the mammalian creatures were minute and furtive; their successors in the Tertiary era became large and dominant. Again, primitive man existed at a low stage of development for a long period, and then rose quickly to biological dominance, within the last ten or twenty thousand years.

(iii) Once the new type is well established, it usually evolves into a number of specialized branches.

5. Darwin's Views.—(i) Darwin assumed that the minute differences which distinguish members of the same brood or litter from one another are inheritable, that each variation will in turn give rise to other variations in the same direction, and that in this way the originally small variations are increased by accumulation. (ii) His hypothesis of " natural selection ", the universal " struggle for existence ", and " the survival of the fittest ". (Explain what he really meant by these things: those variations which give some advantage to the individual over his fellows are the determining factor.) (iii) His subsidiary hypothesis of sexual selection. (iv) He assigned some weight to the environment, and to the effects of use and disuse, and thus far was in agreement with Lamarck—that change in environment induces a tendency in animals to vary slightly in all directions, and that those variations which happen to suit the environment are preserved and affect the character of subsequent generations. (v) He regarded the facts of heredity as the fundamental facts, and believed that natural selection is sufficient to account for the evolution of the most complicated organs, even though he always admitted the existence of other contributory factors.

The vast influence of Darwin's work is due to the fact that he seemed to establish on a firm basis the principle of the transmutation of species, as an induction resting on a vast accumulation of data obtained by observation and experiments of various kinds. From this time onwards, organic evolution was no longer looked upon as just a speculative hypothesis, but as a well-established principle generalized from indisputable facts. But as to Darwin's mode of " natural selection ", biologists are divided in opinion.

6. The Three Main Evolutionary Factors.—Biologists agree that the three principal evolutionary factors are: (i) *the living organism* itself as a self-adapting creative agent, adjusting itself to its environment; (ii) the *functions* of the living organism, their use and disuse; (iii) the *environment* which stirs the organism to action, moulds it, and modifies it. But biologists

differ as to the relative importance of these; some stress the first, some the second, and some the third.

7. VARIATIONS.—Darwin's theory depends essentially on the cumulative increase of continuous variations in the direction of utility, but some biologists are not convinced that minute variations have any selective value, if only because of the enormous amount of time that would be required to produce such changes as the evolution of species contemplates, and they have urged the recognition of a theory of saltatory variations, i.e. of " leaps " from species to species. All biologists agree that variations of one kind or of the other are the real building stones of evolution, no matter what may be the *cause* of the variations.

8. EVIDENCE OF SALTATORY VARIATIONS.—The work of De Vries, and his law of " mutations "; his term " species " appears to correspond to the ordinary term " variety ". The work of Mendel; hybridization. What we may learn from breeders' work. Bateson's championship of saltatory evolution. The geater merit of Mendel's work is that it is experimental, but it is very far from yielding certainty.

9. MUTATIONS AND DIMINISHED VITAL ENERGY.—Mutations or " sports " are comparatively common among cultivated plants and domestic animals which live under unnatural conditions. They are exceedingly rare in wild nature. They seem to render their possessors more or less crippled or deformed, as compared with the type. A pronounced " leap " from type seems to result in a diminution of vital energy and therefore of resistance. Consequently, we must not place too much confidence in the assumption that mutations have ever led to forms which are capable of survival under the conditions of wild life.

10. WEISMANN'S VIEWS.—Weismann's views are really an extension, to the germ-plasm, of Darwin's hypothesis of natural selection. Weismann maintained that there was a

struggle amongst the determinants, and that the most vigorous survive.

11. Cause of the Variations.—The variations seem to *originate* in changes that first take place in the germ-plasm, but how we do not know. No hypothesis that has hitherto been put forward gives a satisfactory explanation. Precisely how a change in a determinant (or gene, if it be a gene) is effected by any of the influencing factors—use, disuse, environment, and so forth—we simply do not know.

12. The Present Position.—The constancy of specific characters within the span of observation afforded by a human life is the most familiar of all the facts of natural history. Even a period of 10,000 years seems utterly insufficient to bring about a specific change. Presumably species are still in process of formation, the main factors at work being geographical isolation with enforced physical and chemical changes, enforced change of habit, enforced competition with new environment, and new stimuli to germinal energies themselves. But how these various factors actually bring about adaptive results in the germ-plasm we do not know. The secret is probably hidden in the chromosomes.

The weight of evidence is probably on the side of discontinuous variations as a prime factor, but the evidence is anything but conclusive.

That the chromosomes consist of units of some kind is highly probable, that small variations take place amongst these units is also highly probable, and that natural selection then sets to work amongst them is scarcely less probable. But we cannot say more than this.

13. Abiogenesis and Biogenesis.—The work of Tyndall and Pasteur, and the general acceptance of the law of biogenesis. At present the law is of a negative character; it asserts that, at present, there is no known evidence of living organisms arising from non-living matter.

Conceivable origin of life. Kelvin's views necessarily rejected: he merely shifted the main question to another planet. Life *may* have arisen from non-living material when conditions differed widely from the conditions that obtain at present. From some colloidal carbonaceous slime, activated by ferments? from cyanogen? from simple carbohydrates which captured nitrogen from ammonia, and so led the way to amino-acids and thus to proteids? We can only speculate. Biologists are sometimes a little violent in their emphasis over this question, but they cannot do more than express an opinion.

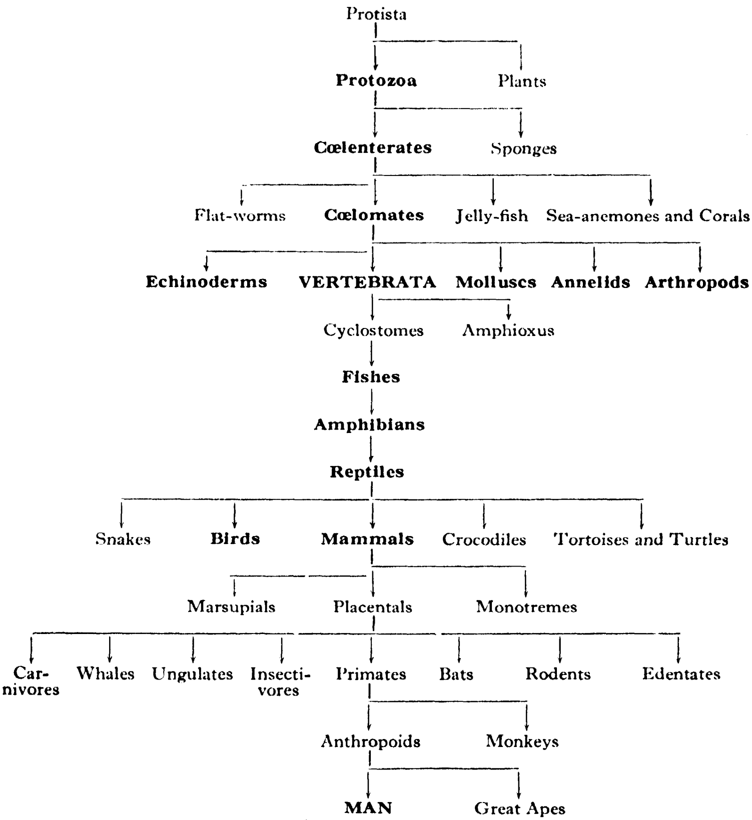
The Biologist's Genealogical Tree

If the evolution of species be accepted as a fact, some kind of genealogical tree showing the descent of Primate from Protozoan logically follows. The traditional method of phylogenetic research has led to the belief that each group of animals has been derived from one of the known lower groups. It is generally believed, for instance, that the Arthropods are derived from the Cœlomates. But biologists are now beginning to believe that the early ancestors of such large fundamentally isolated groups as the phyla, all originated far back in pre-Cambrian times.

In constructing a genealogical table, all sorts of questions arise. For instance, were the Vertebrates descended from the Annelids or from the Arthropods? There is an obviously close relation amongst the three highly specialized groups, but all three *may* have been, and probably were, descended independently from a common ancestor. Even experts differ in opinion over such questions, for there is generally an element of doubt about the evidence: some facts seem to point in one direction and some in another. Still, the experts are in agreement about the general genealogical sequence.

For instance, if we consider the early Metazoa, the Cœlenterates are obviously lower down the scale than the Cœlomates, for they have only a single gastro-vascular cavity, and no anus, whereas the Cœlomates have developed further, having both a body cavity and an intestinal cavity.

If the pupil's knowledge of zoology includes a knowledge of the essential differentiæ between the phyla, he ought to be able to appreciate the following table. In fact he should memorize it. The main stem from Protist to man is easily recognizable in the main vertical column. Some of the branches are scarcely less interesting, if only because they include some of the complete phyla. (The phyla are shown in clarendon type.)



The following tables are useful supplements to the genea-

logical tree. The pupil should check them as far as his knowledge of zoology permits.

Evolutionary Stages.	Representative Animals.
No formed nucleus.	Bacteria.
Nucleated cell.	Amœba.
Cell organs.	Vorticella.
Mouth.	Hydra, sea-anemone, corals.
Nerve-ring.	Jelly-fish, siphonophora.
Central nervous system.	Flat-worm, tape-worm.
Cœlome, elaboration of heart.	Echinoderms, bivalve molluscs, earth-worms.
Primitive head.	Primitive molluscs, lower arthropods.
Elaboration of brain and head.	Molluscs, fish, higher crustacea.
Terrestrial life in moist places.	Land molluscs, amphibia.
Terrestrial life fully developed.	Many insects and arachnids, reptiles.
Elaboration of instincts.	Higher insects, spiders.
Associative memory; warm blood.	Birds, mammals, higher reptiles.
Evolution of intelligence.	Higher primates.
Reason, speech, use of tools and fire.	Man.

Phylum.	Nucleated Cells.	Digestive Cavity.	Body Cavity.	Backbone and Head.	Jaws and Paired Limbs.	Bone.	Terrestrial Life.	Amnion.	Temperature Regulation.
Protozoa ..	×								
Cœlenterata	×	×							
Cœlomata ..	×	×	×						
Cyclostomes	×	×	×	×					
Cartilaginous fish	×	×	×	×	×				
Bony fish ..	×	×	×	×	×	×			
Amphibians	×	×	×	×	×	×	×		
Reptiles ..	×	×	×	×	×	×	×	×	
Birds and Mammals	×	×	×	×	×	×	×	×	×

CHAPTER XXII

Geology and Palæontology

The Geology Commonly Taught

It is unlikely that geology will become a substantive subject of science in schools, if only because of the difficulty of devising a suitable course of practical work. And yet no branch of science lends itself more readily to inductive treatment. In fact, practically the whole subject has been worked out by inductive methods. There is really no other way. And the subject has been placed on such a firm basis that it is to be regretted it is not given greater prominence in the school curriculum.

Geology is essential for the full understanding of both geography and biology, and, in point of fact, certain elementary sections of the subject are almost universally included in all school courses of physical geography. For instance:

1. The earth as a member of the solar system; form, size, movements.
2. Material of the earth's crust; probable condition of the interior.
3. Work of air, rain, rivers, oceans, ice, glaciers.
4. Denudation, disintegration, transport, deposition.
5. Rock-building by sediments.
6. Volcanoes and earthquakes; earth movements, heat and lateral pressure, secular upheavals and depressions.

Further work sometimes, but not very often, included:

1. Architecture of the earth's crust: stratification, forms of bedding, alternations of strata, overlap, lapse of time represented by strata, groups of strata, order of superposition, joints, inclination of rocks, curvature, cleavage, dislocation.

2. Lessons from the Great Barrier Reef, and the shallow waters off Queensland.
3. Rocks and minerals. Properties of minerals—crystalline form, hardness, specific gravity, cleavage, lustre, colour. Classification.
4. Sedimentary rocks and their classification. Softness or hardness of a rock no criterion of its geological age.
5. Volcanic rocks and plutonic rocks. Compression. Mountain building.
6. Geological maps.
7. Evolution of the earth itself. Failure of the nebular hypothesis because of the resulting unsatisfactory distribution of energy in the solar system. The meteorite-aggregation hypothesis. The sun-bolt hypothesis.
8. The figure of the earth as determined by variation in gravity over its surface; the rigidity of the earth; methods of estimating time that has elapsed since final consolidation of earth's crust (10^9 to 10^{10} years by radio-activity calculation).

I have seen some useful outdoor work done in quarry and in railway cutting, the pupil being provided with hammer, chisel, knife, magnet, lens, and (for testing carbonates) a small bottle of HCl. I have also been present on one or two useful geological excursions, once in a very successful hunt for microzoa amongst the shale of a disused quarry. Indoor work is necessarily largely of the museum type; the enthusiastic boy likes it, the average boy does not, and it is seldom of very great value. A certain amount of chemical analysis is possible, though it seldom leads far. The cutting of rock-sections for the microscope is beyond boys' skill. On one occasion I saw two boys ploughing their way through Bauerman's two books on mineralogy, and not only had they become quite expert in the use of the goniometer, but they had made, from prepared cardboard " nets ", some excellent models of crystals. But such work does not take boys to the heart of the subject, and I am sceptical of its value.

Why Some Knowledge of Palæontology is Necessary

One reason, perhaps the main reason, for including geology in a school science course is because of the paramount importance of palæontology in the teaching of biology. But palæontology is very rarely taken up seriously in schools. For its proper understanding, a preliminary treatment of most of the geological topics mentioned in the last section is desirable. In particular, a study of stratification, in some little detail, should be included. Pupils should be familiar with the accepted terminology—the main geological time-division " Era " with its subdivision into " Periods ", and the further subdivision into " Epochs ", and the respective corresponding terms for geological strata, " Groups ", " Systems ", and " Series ", though " epochs " and " series " will seldom be mentioned unless the subject is taken beyond an elementary stage. There should also be included estimates of the age of the earth in geological time, and of the thickness of successive deposits; also how these estimates were made, and why geologists and physicists are much more nearly in agreement now than they were fifty years ago.

The following topics might be included, but unless the learner is familiar with a fair number of typical living zoological forms, his study of palæontology is likely to be very unprofitable.

Suggested Topics for Inclusion in a School Course

1. *What Palæontology is.*—Reasons for concluding that fossil forms are relics of animals or plants which were once alive.

2. *The Eighteenth-century Discovery* that each system of sedimentary rocks contains a definite assemblage of fossils, some of which are characteristic of that system.

3. *How a Stratum may be traced* across a country by means of its characteristic fossils.

4. *Evolutionary Advance.*—The obviously graded development of animal forms in the successive strata from the older below to the newer above. Only in the newer rocks is there any evidence of the highest group of animals—the mammals. The vast thicknesses of the earlier strata containing only invertebrate animals; then the appearance of fishes, then of amphibians, then of reptiles and birds, then of mammals.

5. *Extinct Species:* their position in the record.

6. *Conditions of Entombment.*—To be entombed and become a fossil, an animal or plant must (1) possess a skeleton, and (2) be covered up by a deposit. Since there are few places on land where material is being deposited to any large extent, terrestrial animals have *relatively* little chance of being preserved. The fossil remains of marine life are by far the most valuable.

7. *The Varying Composition of the Fossil Skeleton:* chitin, silica, carbonate and phosphate of lime, calcite and aragonite, woody or corky tissues. Hence some are more readily preserved than others. How and why some skeletons disappear and others are preserved.

8. *The Conditions in which Fossils Occur.*—(i) The entire original organism, e.g. the woolly rhinoceros and the mammoth frozen in mud and ice; insects and plants in fossil resin (amber). (ii) The skeleton alone, the organic matter being lost, as in certain shells in the pliocene beds. (iii) The original matter carbonized, as in some plants and some animals with chitinous skeletons, such as graptolites. (iv) A mould of the skeleton formed, the skeleton proper disappearing, especially when this consists of aragonite; water charged with carbon dioxide carries off the skeleton. (v) Petrifaction: original material replaced by another material. (vi) Imprints: no part of the animal itself.

9. *Uses of Fossils.*—(i) Fossils afford evidence of conditions under which the containing rocks were deposited, e.g. a deposit may be marine, or one formed in fresh water, or on land. (ii) Evidence of the climate of the period of deposit. (iii) The depth of the sea in which a stratum was deposited may be estimated when the fossils are represented by living specimens. (iv) Chronological value: once the order of successive formations has been determined, the characteristic fossil of a stratum enables us to refer any newly discovered formation to its proper place in the geological record. (v) Fossils often represent the ancestors of modern species. (vi) The fossils of animals which have become extinct (e.g. Graptolites, Trilobites) throw light on the relationship of existing animals and plants; in some cases, ancient forms are obvious links between now quite distinct groups. (vii) Evolutionary evidence: by the study of the stratigraphical succession of fossil forms, the phylogeny (race-history) of animals and plants can be traced with certainty. Many of the classes and some of the orders of most of the great phyla of animals are found in the very early strata, and most of them in the Cambrian; but each is represented by its most rudimentary genera. Progress from one geological system to another from below is obvious. It is often easy to note the time of appearance of each great group; the Mezosoic mammals, for instance, are all marsupials, and not until Tertiary times do placentals appear; none but animals without a backbone have ever been found in the oldest fossiliferous rocks; fishes have obviously flourished long before any lung-breathing backboned animals; the cold-blooded amphibians and reptiles appear, successively, before the warm-blooded birds and mammals; man appears at the end. Linking forms may often be noted: reptile-like birds, bird-like reptiles, amphibians with affinities to fish, fish with affinities to the amphibians, tapirs with affinities to horses, forms intermediate between camels and llamas, and so on, all invaluable facts for determining ancestral lines.

10. *Difficulties about the Evolutionary Hypothesis.*—(i) Some forms have survived without change from very early times, e.g.

lingula from Cambrian times, and some brachiopods from Jurassic and Cretaceous times. (ii) There is very little evidence of the actual origin of the great phyla of the animal and plant kingdom; most of them seem to have appeared very suddenly. (iii) There is a general absence of transitional forms amongst plants; ferns, equisetums, and lycopods appear as far back as the Old Red Sandstone, in even more complex structures than their living descendants. The oldest known dicotyledons are those of cretaceous formation; they contain in the same deposit representations of the three great divisions, apetalous, monopetalous, and polypetalous. The general inference is that the geological records are very imperfect.

11. *Examples of Undoubted Lineage.*—There are well-known instances of undoubted intermediate forms between distinct species: (i) the series of fossil *horses* extending from the Eocene to the Pliocene, obtained from the rocks of the American continent; the evolution of the skeletal peculiarities of the modern horse strike the eye at once; (ii) the evolution of the camel: the skeletal development is again easily seen; study the consolidation of the bones of the foot, and the reduction in the number of incisor and pre-molar teeth; (iii) the freshwater snail *Paludina*. In all three cases, first show the pupils the youngest and the oldest forms, which will certainly convey the impression of distinct species; then put in position all the intermediate forms, and the evolutionary development is so obvious as to be impressive.

12. Select a few type fossils characteristic of each system, and arrange them in chronological order. Invertebrates do not so readily tell their own story as vertebrates do, but a wealth of suggestive material is described in Mr. Henry Wood's *Invertebrate Palæontology*.

* For figures of the evolving horse, camel, and elephant, see Lull's *Organic Evolution*, pp. 577–640; for the snail series, see Haldane and Huxley's *Animal Biology*, or Lull's *Organic Evolution*; an evolutionary succession of 17 forms is given in both cases. Plate IV of Lull's book shows skeletons of horse and man side by side, with the corresponding bones marked; model skeletons themselves may be seen in one of the bays off the main hall of the Natural History Museum. The corresponding bones are all accurately named, and the close relationship of the mammals so apparently wide apart is seen at once.

13. Pupils should know that the whole succession of marine fossil-bearing rocks in Western Europe—the most favourable region in the world—had been clearly ascertained before the idea of organic evolution was accepted by geologists. It was only after the publication of Darwin's work in 1859 that the meaning of the order in which fossils were known to occur became evident.

14. Let each pupil make out, in "gridiron" form, his own tabulated stratigraphical chart, say with six vertical columns, these being headed (i) Eras (groups); (ii) Periods (systems); (iii) Thickness of sedimentary rocks laid down (in miles); (iv) Estimated age (in years); (v) Typical rocks; (vi) Typical fossils. The chart should not be overloaded; let it contain what can be remembered. Many boys will already have learnt from their geography such well-known rocks as the London clay in the Eocene period, chalk in the Cretaceous period, coal and ironstone in the Carboniferous period, sandstone in the Devonian, slates in the Cambrian, and gneisses and schists in the pre-Cambrian. As regards fossils, the great thing is to note when each new phylum of animals appeared, or any noteworthy intermediate forms (e.g. archæopteryx and pterodactyls in the Jurassic, and intermediate mammal forms in the Eocene), or forms which have disappeared altogether (e.g. Graptolites in the Silurian, and Trilobites in the Permian); in short, any main facts supporting the evolutionary hypothesis. The appearance of the dicotyledons and of the large cryptogams in the carboniferous period should also be noted, though animal forms will, for the present purpose, naturally receive first attention.

The chart should be so constructed as to give maximum help to the eye. For instance, since the total thickness of the rocks laid down is about 40 miles, the 40 miles might be represented by 5 inches, i.e. on a scale of 8 miles to the inch. Hence the 5 miles of thickness of the carboniferous system would be allotted a space across the chart of $\frac{5}{8}$ inch, the 3 miles of the cretaceous, $\frac{3}{8}$ inch; and so on.* And all the

* Alternatively, scale to time, instead of to thickness of deposit. The two scales do not by any means corresponds.

selected type fossils should be sketched, no matter how roughly. But let the selection be small, *and let it be learnt.*

15. Let the pupils construct a separate chart on a larger scale, showing the divisions of the post-Tertiary Era, with the Pleistocene and Recent Periods (with the Great Ice Age, and the Palæolithic, Neolithic, and Bronze Ages); the Glacial, Palæolithic, and more recent deposits, with their human relics; fossils of the great mammals now extinct (mammoth, &c.), and human remains. Impress on the pupils that all estimates as to thickness and ages of deposits must be received with great caution; they are at best only very rough approximations.

Simpler and differentiated tabular schemes may be preferred. We append one or two. But encourage boys to prepare their own tabular schemes. Scaled " gridiron " schemes are always to be preferred.

The first table shows the geological eras and periods, with respective time estimates.

Rough Estimates of Time in Years.	Era.	Period.	Age.	Rocks.
1,000,000	Post-Tertiary	Pleistocene, &c.	Man	Mainly sedimentary
60,000,000	Cainozoic	Pliocene, &c.	Mammals	
200,000,000	Mesozoic	Cretaceous Jurassic Triassic	Reptiles	
400,000,000	Palæozoic	Permian Carboniferous Devonian Silurian Ordovician Cambrian	Amphibians Fishes Invertebrates	
400,000,000 (probably much longer)	Pre-Cambrian	Proterozoic Archeozoic	Evolution of Invertebrates Evolution of Unicellular Life	Mainly metamorphosed; igneous predominant

The first column cannot be shown accurately to scale, as the 1,000,000 years estimated for the age of man is less than 1/1000 of the estimated time that has elapsed since the beginning of the evolution of unicellular life.

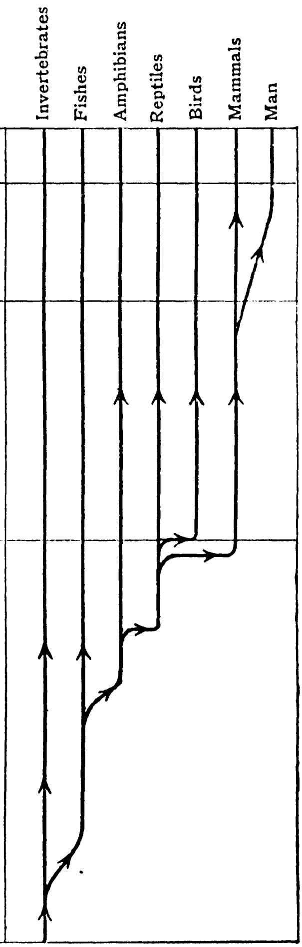
The second table shows in a larger scale the 1,000,000 years estimated to represent the age of man, the post-Tertiary era. The first 100,000 years are not to scale. It is perhaps 5000

Years Back.	Period.		Epoch and Age.			Remains of Man.
		Historic	Iron			Modern man
			Bronze			
5,000 10,000	Recent			Neolithic		
		Pre-historic		(Unknown)		
100,000						
					Magdalénien	Cro-magnon man (true man)
200,000					Solutréen	
300,000					Aurignacian	Numerous remains of prehistoric man found from these ages; also of their rough implements.
400,000			Stone	Palæolithic		
500,000	Pleistocene or Glacial				Moustérien	
600,000						
700,000					Acheuléen	
800,000					Chelléen	
900 000						
1,000,000				?Eolithic		Eoliths *may* be of human origin.

years since the Bronze Age, and 8000 or 10,000 since the Neolithic Age. Between the Neolithic and Palæolithic Ages there was a transition period probably extending over many tens of thousands of years, about which we know nothing.

Here is another suggestive table, modified from Haldane and Huxley,* with which pupils should familiarize themselves:

Age of Man	Post Tertiary	Recent Pleistocene
Age of Mammals	Cainozoic	Pliocene Miocene Oligocene Eocene
Age of Reptiles	Mesozoic	Cretaceous Jurassic Triassic
Age of Amphibians		Permian Carboniferous
Age of Fishes	Palaeozoic	Devonian
		Silurian
Age of Invertebrates		Ordovician Cambrian



* The pupil should see the table in its original form, with its aids for visualization.

Lastly, a table showing the approximate thickness (in miles) of geological deposits:

Recent and Pleistocene	1	1	Post-Tertiary
Pliocene	1	8	Cainozoic
Miocene	2		
Oligocene	2½		
Eocene	2½		
Cretaceous	3	7	Mesozoic
Jurassic	1½		
Trias	2½		
Permian	2½	22	Palæozoic
Carboniferous	5		
Devonian	4½		
Silurian	3		
Ordovician	3½		
Cambrian	3½		

The Descent of Man

The pupil should be taught to sift carefully the evidence advanced concerning the history of man since his emergence from lower Primate stock a million years ago. Some such scheme as the second of the above tables should be provided, if only to show the pupil the enormous length of primitive palæolithic culture, when primitive man was slowly struggling upwards. The duration of the subsequent cultures (neolithic, bronze, iron, present-day) are by comparison insignificant. Although man emerged from lower stock probably a million years ago, he was still semibarbarian as recently as 10,000 years ago, though his external appearance even 30,000 or 40,000 years ago differed hardly at all from that of man at the present day. An examination of pre-dynastic Egyptian mummies shows that types have certainly not appreciably changed in 10,000 years, but man has had a hundred times 10,000 years in which to reach his present state since his rationality dawned.

It may be well to give the pupils some of the chief reasons for believing that man is of anthropoid origin.

1. The blood of man and that of the great anthropoid apes give almost the same reactions. (It has been definitely established that the affinity of one species of animal to another may be determined by comparing the reactions of their blood.)

2. The living anthropoid body possesses about the same susceptibility to infection as does the body of man.

3. The brains of man and the anthropoid are almost identical in their structural organization. The only real distinction is a quantitative one.

4. The very complex structures connecting the human embryo with the maternal uterus are found in the anthropoid uterus, and in no other.

5. The same vestigial structures occur in the bodies of man and anthropoid.

6. The anthropoid mother fondles, nurses, and suckles her young in the human manner.

Palæontology points to certain definite conclusions, and these the pupils should know.—*Homo sapiens*, the species to which belong all the living races, and with almost equal certainty all the races of which we have historical knowledge, is not the unique member of the human family. Four or five other kinds of man, sufficiently distinct to be placed not only in different species but in different genera, have existed in the past. They differed in the capacity of their skulls, in their jaws, in the curve of their backbone, and in their gait. The brain of *Pithecanthropus*, the most ancient of the fossils, was almost halfway in weight between the weights of the lowest living Australian and the gorilla; the brain of Piltdown man, the next in order of time, was larger, but still small, and these two brains were defective in the regions concerned with speech and with the higher functions of the mind. On the other hand, the brain of Neanderthal man, although curiously shaped, was large, and the association of the fossils of this race in many parts of the world with flint instruments and a peculiar type of grave showed that its members probably had a definite culture and some kind of religious belief.

The fossil evidence proves that there has been a process of evolution, *but it is not sufficient to establish exact pedigrees*: impress this on the pupils' minds. We do not know what were the characters of our own ancestors in the Pleistocene Age, or whether any of the other kinds of men were (so to speak) our grandparents or our great-uncles.

The science teacher should exercise great caution in dealing with the history of primitive man. Some of the popular books are seriously misleading. One or more standard works should be consulted. Dr. G. G. McCurdy's *Human Origins* and Professor Osborn's *Men of the Old Stone Age* may be suggested.

Palæontology should be taught with the main purpose of providing the pupils with evidence clearly understood and convincing in character of the story of evolution. Avoid unnecessary details. Select the most telling facts. Make the reasoning cogent. Do not hesitate to point out doubts and

difficulties, to say outright that many things are not yet proven, that all our time-estimates are possibly a long way out, and that the whole hypothesis may break down, though this is not probable.

CHAPTER XXIII

Bacteriology

The Present Importance of the Subject

A good way to begin this subject is to discuss the distinction between the " poisons " that do not multiply and those that do. The effect of a poison like arsenic or strychnine is limited to the size of the dose. If a dose just large enough to be fatal is given to a rat, we are not surprised to discover that the flesh of the dead rat is poisonous. But if the dead animal were cut in small pieces, nobody would expect to find that each little bit was poisonous enough to kill another rat. Yet it had been noticed for centuries that *some* kind of multiplication in the bulk of poison seemed to occur in the case of many contagious diseases, and the conception gradually grew up of a living contagium that could grow and multiply. Eventually, in the middle of the last century, the anthrax bacillus, now known to be the exciting cause of splenic fever, was seen in the blood of a sick animal, and that observation led to investigations which have gradually built up the whole subject of bacteriology.

Very little practical work in bacteriology is possible in school science courses, but there is a considerable range of facts which should be in the possession of all educated persons and which therefore should be taught. Everybody ought to know something of the work of Lister, Pasteur, and Koch, and of the trend of modern research into preventive medicine. We suggest some headings, with a few running comments, for teaching purposes.

1. *Lister.*—One of the greatest discoverers in the sphere of preventive medicine. He did for the craft of surgery what John Hunter had done for its science. When he began his work, operations were few, owing to the danger of putrefaction in the wound, followed in almost all cases by death. Lister's chief interest—the problem of the healing of wounds. How he showed that inflammation was a reaction of the tissues to a noxious stimulant from without. When Pasteur had proved that putrefaction was caused by minute organisms suspended in the air, a method of prevention at once occurred to Lister—to apply to the wound some substance which would destroy the micro-organisms without injuring the body-tissues. Later, he devised a method by which the organisms might be destroyed before they had even entered the wound. He thus discovered the *nature* of wound diseases.

"Antiseptic" and "aseptic" methods. Difference. No real clashing.

The Lister Institute and its objects.

The fierce controversy about Lister's work and the stupid scepticism of the medical profession. Use this as an illustration, in the history of science, of the inevitable opposition to new truths. (Other instances: Harvey's work, Pasteur's work, and the work of certain men of the present day.) Lister worked on imperturbably, and ultimately revolutionized the practice of surgery. The main characteristic of the man—a search for true facts, and a fearless disregard of accepted medical opinion.

2. *Pasteur* investigated the rôle played by bacteria in various familiar natural processes, such as putrefaction, decay, and fermentation. He demonstrated that putrefaction and decay were not fields for the "spontaneous generation" of life, but were manifestations of chemical disintegration due to the metabolic activities of *micro-organisms engaged in satisfying their need of food*; also that fermentation was caused by the effort of living and growing yeast cells to satisfy their nutritional requirements. Pasteur was the real founder of the science of bacteriology. Lister and Tyndall acknowledged the tremendous change

wrought in all conceptions of disease through the work of Pasteur.

By 1865, the more enlightened medical world had realized that Pasteur's discovery (that particular fermentations were produced by specific microbes) indicated the possible nature of the various *contagia viva* responsible for disease. It was appreciated that *diseases breed true*, as dogs and cats breed true, and that they did not arrive *de novo*, although their ultimate origin was as mysterious as the origin of species of higher animals or plants.

3. *Koch* placed bacteriology on the firm scientific basis of an independent branch of biology. In 1876, he showed that a specific bacterium (*B. anthracis*) was the cause of anthrax or splenic fever in cattle. His success stimulated many investigators to research along the lines of the germ theory. In 1882 he conferred great benefit upon practical workers in this field by his invention and application of *solid culture media*, a technical device by which it became possible to isolate single species of bacteria and obtain them in pure culture. Great discoveries immediately followed upon this important technical improvement.

4. *Present-day Bacteriological Workers* tend to specialize in one of two directions. (i) Pathologic bacteriology: considerations given chiefly to the effects produced upon the animal body by the presence of bacteria and their toxins, to the distribution of the germs within the body, and to the reactions brought about by bacterial invasions. (ii) Hygienic bacteriology: this deals more particularly with the channels by which bacteria leave the human body and pass into the outer world; with the mode, duration, and life of disease germs in water, soil, and air; and with the avenues by which these diseases are able again to approach and infect healthy individuals.—A common meeting-ground is found in research on immunity.

5. *Making Cultures.*—In the early efforts to grow bacteria

in liquid solutions, every drop swarmed with many different kinds. Then came the device of using a medium which would remain a solid jelly even at the right temperature for growth. A drop of the fluid containing bacteria was shaken up with this jelly while it was still liquid; the medium was then poured out on a plate where it set into a layer of jelly within which the scattered microbes were held fast. When growth took place, the plate became dotted with separate colonies, each the growth of a single bacterium. If the purity was not obtained by one culture, the process was repeated, infection being used from that colony which seemed most pure. It thus became possible to trace the visible characters of each species through their many phases, and to explore their physiological and pathological properties.

6. *The sources of our knowledge of the life-histories and the different types of bacteria.*

(i) *From pure cultures.*—By this means bacteria which are the specific exciting causes of such diseases as cholera, typhoid fever, tetanus, diphtheria, tuberculosis, and plague, have been identified.

(ii) *Discovery of insects as disease-carriers.*—This has led to exact knowledge of the causes of such diseases as malaria and sleeping-sickness. In these cases, the microbes are animals, and multiply in the blood of their vertebrate host. A biting insect—mosquito, fly, or tick—in pursuit of its own food, accidentally absorbs and carries the microbe from one animal to another. It took a long time to ascertain with certainty this causal connexion, and progress was further delayed by the natural misconception that the biting fly carried the infection mechanically, as a dirty needle might carry it in surgery. What really happens in most cases is that the microbe goes through a necessary stage of its life-cycle in the body of the insect, each kind of parasite being able to fulfil its destiny only if it is absorbed by the right species of insect.

(iii) *The use of the ultra-microscope.*—The object is placed on a dark stage, and a very strong beam of light is sent horizontally through it. By this means it has been possible to detect very minute and very transparent mobile organisms known as spirochætes, which elude observation by ordinary microscopic methods. In the ultra-microscope, the twisting spirals become conspicuous shining objects. By this means the exciting causes of yaws and other diseases, probably including yellow-fever, have been discovered. The use of sunlight in the ultra-microscope allows an object as small as 0·004 μ to be visible.*

7. *Bacteria as objects of study.*

(i) *Bacteria are minute unicellular organisms*, usually classed as plants rather than as animals. But they lack chlorophyll, and it is probable that they occupy an intermediate place between plants and animals. The general dimensions are from ·05 μ to 2 μ, though some are smaller, so small as to elude detection.

(ii) *Morphology, &c.*—Each type has distinctive visible characters, such as size and shape. But they are subject to modification by food, temperature, and the nature of the surroundings. They may appear singly, in pairs, in fours, in chains, in clusters, in cubical masses, &c. The characteristic forms are spheres, short rods, long rods, filaments, commas, short spirals, long spirals, curves, &c.

(iii) *The naming of the principal forms.*—The three main forms are typified, respectively, by a ball (*coccus* or *micrococcus*), a rod (*bacillus*), and a spiral (*spirillum*). More bacilli are known than cocci, and more cocci than spirillæ.

(iv) *Response to environment, &c.*—Growth and cell-divi-

* The principle of the ultra-microscope is quite simple. See, for instance, Dr. Mellor's *Modern Inorganic Chemistry*, p. 143, &c.

sion; spore formation; effects of physical and chemical agents—temperature, light, moisture, oxygen supply, food supply.

(v) *Culture study.*—The use of cotton plugs; the need of scrupulous sterilizing; preparation of culture media (beef broth, gelatin, agar, &c.); methods of obtaining pure cultures; separation of bacterial species; thermal death-point of different bacteria and how determined; staining reactions.

(vi) *Work with the microscope.*—Examination of living bacteria and of stained bacteria.

8. *Example of Bacteria.*—(i) *Cocci*: staphylococci (in boils), streptococci (in erysipelas), pneumococci (in pneumonia); (ii) *bacilli*: the anthrax bacillus, the diphtheria bacillus, the tubercle bacillus; (iii) *spirillæ*: spirillum choleræ (in cholera). The number of known bacteria is very large, and they are known only to experts.

9. *Filter Passers.*—Certain micro-organisms, of which very little is known, are so minute that they pass through a filter. If a solution containing ordinary microbes be passed through a Pasteur filter, the organisms themselves are kept back; but in certain cases, including even those producing a malady as common as foot-and-mouth disease, the filtered virus retains not only its infectious character but its power of multiplication. In this way, the conception of a filter-passing microbe has arisen. A few of these are said to be visible under the higher powers of the microscope, and some observers certainly claim that they are visible with the ultra-microscope. Really, however, the ultra-microscope has added very little to our knowledge of them. It is believed that the unknown agents of measles and scarlet fever are amongst them.

10. *Toxins and Anti-toxins.*—Ptomains and toxins as poisonous metabolic products of bacteria: our limited knowledge of them. The remarkable potency of bacterial toxins.

Toxins as analogues of enzymes: characteristic quality of a true toxin—its ability to evoke the formation of a specific antibody, an *anti-toxin*, when it is injected into the body of a suitable animal species.—The diphtheria bacillus as an example: it grows in the throat and liberates into the blood a poisonous protein which is particularly dangerous to the heart; this protein is called diphtheria toxin. When ground-up dead diphtheria bacilli are injected into a horse, antitoxin is developed in the blood, and this will protect human beings against the toxin. Somehow, the anti-toxin puts the toxin out of action. But only a few bacteria kill in the rather simple way employed by the diphtheria bacillus; hence few diseases can be cured by anti-toxins.

11. *Theories of Disease.*—In ancient times, the causes of disease were looked upon as due to some sort of supernatural intervention. It did not seem to occur to the ancients to undertake a rational investigation. It was known to the Romans, for instance, and before them to the Egyptians, that sleeping under a *canopeum* afforded a large measure of protection against marsh fever; and, less than a century ago, physicians were still framing hypotheses to explain how it was that a net placed above the sleeper could hinder the access to him, or diminish the virulence, of the " miasma " which, *ex hypothesi*, produced the disease by rising from the ground. Before the time of Ross, nobody seemed to argue that the chief business of a mosquito net must be to exclude mosquitoes!

In the Middle Ages, the old idea of supernatural causes gave place to the view that the cause must be sought in some natural phenomenon—perhaps the deleterious changes in the air from miasms emanating from the soil, the effluvium given off by unburied bodies, and the like. There were also those who believed that telluric influences like earthquakes and floods, or celestial phenomena like eclipses and the conjunction of planets, were responsible.

At the present day the germ theory of disease is universally accepted. The idea that disease might be contracted by con-

tact with the sick was definitely established in the sixteenth century, though it was recognized that this did not explain all epidemic diseases. By degrees the doctrine of contagion clearly emerged, and the work of Schwann and others prepared the way for Pasteur.

Examples of diseases caused by definitely discovered germs are diphtheria, tuberculosis, cholera, tetanus, Malta fever.

Examples of anti-toxins discovered are that for diphtheria and that for tetanus.

No specific micro-organisms have yet been discovered as causing scarlatina, measles, whooping cough, hay-fever, rheumatic fever, chicken-pox, mumps, influenza, and the common cold, but the germ theory furnishes the most reasonable, consistent, and probable explanation of them all. But we are not *quite* sure that micro-organisms are the cause. There is ground for believing that influenza is spread by contact of man with man, but there is no curative treatment for it, and it remains a "cough-mixture" disease. Once a germ is discovered, a cure ought to come along rapidly. Although, however, the tubercle bacillus has been found, there is no known cure. As for measles, it is not even known how the disease spreads, though contact is suspected.

12. *Research Work.*—The successful research work in certain cases is of great interest. Malarial fever is such a case. It was a long time before the discovery was made that the responsible organism found its way into the blood by the bite of the anopheles mosquito. This knowledge made it possible to attack the disease by draining the pools where the mosquitoes bred, and in other ways. (The mosquito requires for its development shallow pools of stagnant water, and is moreover compelled to come up to the surface of the water at frequent intervals. If the surface of the pools is covered with petroleum, the larvæ are destroyed.) It also became known that quinine is a drug capable of killing the malaria parasite. Another interesting discovery is the part played by the rat flea in spreading the plague, though, so far, no specific drug

for plague has been found. Still another case is the Indian disease Kala Azar; the discovery that antimony is a specific drug is likely to lead to its complete disappearance.

Research workers try to discover (1) how an epidemic disease is caused; (2) how it spreads; (3) how it may be prevented from spreading; (4) how, when a man is attacked, his disease may be treated as effectively as malaria is treated by quinine or Kala Azar by antimony. The " treatment of symptoms " is unscientific, as every practitioner well knows.

13. *Bacteria Exclusive as to their Host.*—No microbe is known to be capable of producing disease in all animals. The power of a microbe to produce morbid effects depends on the nature of the host. The typhoid bacillus if swallowed by man may produce a mortal illness, but it has no effect on cattle.

14. *Immunity.*—Natural and acquired immunity; body resistance to diseases; the unbroken skin as a barrier to micro-organisms, but the moist mucous membrane favourable to multiplication; saliva is germicidal; so is HCl in gastric juice, though swallowed germs *may* get into the intestine.

15. *Metchnikoff's Work.*—The phagocytes.

16. *Dissemination* of disease.

17. *Special Cases of Interest.*—*Small-pox* and the history of vaccination; no specific micro-organism has been isolated in pure culture; the virus can pass through a Chamberland filter; the relation between small-pox and vaccinia (cowpox); vaccination a process of active immunization; germicidal action uncertain.—*Epidemic influenza* (e.g. 1918); uncertain if common influenza between the pandemics is identical with the apparently more violent kind.—*Leprosy* and the new remedy " alepol " (sodium hydrocarpate).

18. *Drugs and their Action.*—*Antiseptics* kill off bacteria in

infected wounds; *anæsthetics* (give examples) allow the surgeon to operate painlessly (explain action); *quinine* poisons malarial parasites in the blood-stream; *digitalis* regulates the action of the heart; *atropine*; *morphia*. Useless drugs; limitations of drugs; the popular confidence in " medicine ". " Cure " fallacies.

19. *Pests and Pest Controls.*—Natural and cultural controls; poison sprays; fumigants; insects as fruit pests and enemies of agriculture; disease carriers, especially common flies and rat fleas; scavengers and pollinators; bites of ants and mosquitoes; stings of wasps and hornets.

20. *Disinfectants and Antiseptics:* difference.—Recognized procedure for disinfection. Sterilization.

21. *Influence of Bacteria on Human Welfare.*—Bacteria disintegrate and destroy dead bodies, attack and kill other living organisms, and certain kinds modify profoundly the composition of the soil.

22. *The Modern Fear of Germs:* unreasonable, and based on inadequate knowledge. The healthy child resists the action of germs, and tends to develop an immunity to the diseases common to his native land.

23. *An Interesting Speculation.*—At some period slightly preceding or during the reigns of the twelve Cæsars, the malaria-bearing mosquito first found a habitat in the Roman marshes. The malaria was not of a severe type, but during two or three centuries it gradually sapped the vitality of the virile Roman population. Does the comparative mildness of the infection account for the prolonged but progressive decline of the Romans?

CHAPTER XXIV

Hygiene

Hygiene as Taught Forty Years Ago

Is hygiene rightly called " science ", or is it an art, or just a code of rules, or a number of " laws "? We often hear of the " laws of health ". What are they, and why are they called *laws*?

Forty or more years ago, the Science and Art Department * included a hygiene syllabus in their directory of science subjects in which examinations were held annually. As the years went on, modifications were introduced, but the substantive headings were:

1. Elementary Human Physiology.
2. Sanitary Engineering and Construction.
3. Water: composition, properties, storage, distribution, purification.
4. Air: properties, impurities, humidity, ventilation.
5. Food: diets. Putrefactive changes in foods.
6. Soil. Drainage. Sites.
7. Habitations. Construction, sanitation, heating, lighting.
8. Removal of water and impurities.
9. Personal hygiene.
10. Clothing.
11. Prevention of diseases.
12. School hygiene.

To the syllabus was added a note to the effect that " it is important that the teaching of hygiene should be illustrated by practical demonstrations carried out in the class ", and suitable experiments were suggested.—Note that the teaching was to be *illustrated by* experiments, not *based* on them. Apparently the teaching was intended to be deductive, not inductive;

* This Department, which was responsible for such higher education as came under the review of the Government, and the " Education Department ", which took cognizance of elementary education, were merged by the *Board of Education Act*, 1899.

experiments were for verification, not for establishing principles. There is a further note: " For the elucidation of the topics covered by the foregoing syllabus, the following suggestions are made for practical demonstrations." Here are three of the experiments:

1. " Show the effects of respiration on air by (i) breathing on a slate, (ii) blowing into lime-water, (iii) blowing into a weak solution of Condy's fluid."

2. " Weigh a dry brick; immerse it in water for half an hour, and weigh and note the amount of absorbed water."

3. " Take a small quantity of solution of tannin and heat in a test-tube. In a second test-tube, dissolve a small quantity of isinglass in boiling water. Mix the contents of the two tubes. The white precipitate produced demonstrates the error of drinking strong tea when eating meat."

Experiments of this type no doubt throw a small amount of light on principles laid down, though unkind people might say that the experiments tend to obscure the principles rather than illuminate them. In any case they are too trivial for a course of serious training in science. That is the trouble in treating hygiene as a branch of school science. The subject consists of such a multitude of different topics that a logically developed course of laboratory instruction rising year by year to higher levels of difficulty and development is scarcely possible. The very slightly related topics are all much of the same order of difficulty, except, of course, such a topic as food-study.

It might be argued that to teach hygiene is to waste time, if only because most pupils have learnt from one source or another what they must do in order to keep fit:

1. Obtain fresh air in abundance, breathe through the nose, practise deep breathing at regular intervals.
2. Wear loose porous clothing.
3. Eat and drink very moderately. Have no food fads, but see that the foods eaten contain the necessary vitamins.
4. Let work, exercise, rest, and sleep be regular.
5. Let all bodily habits be regular.
6. Do not worry.

And yet the great majority of people violate one or more of these excellent rules every day. It is fairly safe to assert, for instance, that most people eat 50 per cent more food than good health demands, and that over-eating is the key to the large proportion of human ailments. It is interesting to observe that those who seem to know most about hygiene can seldom claim immunity from common diseases.

That hygiene should be taught, everybody will agree, if only in order that the pupils may acquire a *reasoned* knowledge of its principles, for then they are much more likely to lay those principles to heart. But should the subject be taught as a branch of ordinary school *science*, or should facts and principles be dogmatically stated?

The Kind of Teaching Advisable To-day

Parts of the subject lend themselves reasonably well to laboratory treatment, but these are topics which are mainly direct applications of physics and chemistry. It is therefore wholly unnecessary to make special provision for the teaching of those topics as part of a course in hygiene as a special subject. For instance, the greater part of the necessary knowledge of the composition, properties, and purification of water and air is best given in the chemistry course; heating, lighting, water-storage and distribution, and matters concerning clothing, are best given as part of the physics course. These topics subserve the particularly useful purpose of illustrating principles laid down in the earlier parts of those subjects. In short, in the teaching of physics, chemistry, and biology, every opportunity should be taken to illustrate principles by reference to the laws of health.

That done, the formal teaching of hygiene will be reduced to a few lessons of a summarizing nature. But unless biology is included as a substantive subject, a certain amount of human physiology and of bacteriology must be provided for. Here are some suggestions. First, in physiology:

1. Structure and care of the teeth. The danger of decayed

teeth. Pyorrhœa. The need of proper mastication. Saliva and ptyalin. The dental surgeon: his functions.

2. The alimentary canal. Structure. Action of ptyalin, pepsin, and other ferments. Digestion and metabolism. Absorption. One important sign of good health an entire absence of a stomach sense.

3. Diets. Chief foodstuffs. Ill-balanced diets. Seasonable diets. Relative digestibility of foods. Dangers of excessive eating. Sick-room feeding. Sugar not a natural food: too concentrated. Alcohol also too concentrated for welfare of body. Patent foods. Canned foods, dried foodstuffs, preserved vegetables. Overcooked foods. Hyperacidity, dyspepsia, constipation, diarrhœa.

4. The heart. General notions of the vascular system. Mechanism of the circulation. The pulse and what it teaches. Arterial schlerosis. Varicose veins. Anæmia.

5. The respiratory system. The mechanism of respiration (this is rather difficult physics). Changes in the blood and in the pulmonary air. Composition of pure and expired air. Deep breathing. Nose breathing. Colds. Adenoids. Influenza; pneumonia; tuberculosis. Gas-poisoning. Principles of modern ventilation.

6. The skin. General structure and functions. Cleanliness. Clothing.

7. The muscular and nervous systems. Fallacy as to the advantage of great muscular development. Fatigue; sleep. Height and weight tables. Physical education. Neurasthenia; self-control. Stimulants.

8. The surgeon and the physician: their respective functions. The terms " doctor ", apothecary, pharmacist, druggist, " chemist " (pharmaceutical and dispensing). Prescriptions.

9. Drugs: their limitations. Patent medicines.

Secondly, in bacteriology:

1. The use of a nutrient gelatine. The presence of bacteria in the atmosphere; such bacteria unable to pass through plugs of cotton-wool.

2. Demonstrate the presence of bacteria in water, in soil, and perhaps in milk. Show their absence from boiled water, boiled milk, and ignited soil.

3. Examples of fermentation. Nature of ferments. Heat of fermentation due to the energy set free in the breaking down of the highly complex molecular structures into simpler compounds.

4. Putrefaction and decay. Why things " go bad ". The possibilities of a dirty dish-cloth in a damp, warm, dark place.

5. Harmless and useful bacteria. Injurious bacteria and the cause of disease. The prevention of contagion.

6. The preservation of foods. Sterilization.

7. Antiseptics, disinfectants, deodorants. The work of sunshine, dry heat, steam, boiling, fire, as agents of beneficent destruction. The home medicine-chest: how it should be stocked; the list of emergency instructions to be pasted inside.

In short courses of this kind, playing a subsidiary rôle, little practical work will, as a rule, be possible. But for the physiology it would be useful to lay open a freshly chloroformed rabbit or guinea-pig, to show the relative positions of the internal organs; the alimentary canal is easily removed after examination, and the heart, the main blood-vessels, and two or three principal nerves may then be exposed to view.

The practical work attempted will depend on the training and experience of the teacher. If the subject has to be taught by, say, the teacher of physical training, no practical work is likely to be attempted, nor would it be desirable, for the courses in physiology at the physical training colleges are strictly elementary in character; not all the colleges have a biological laboratory.

The non-specialist science teacher who teaches hygiene can hardly be expected to treat the subject effectively. And sometimes he—or she—is sadly out of date, depending for the necessary facts on some small text-book written in the eighties, or perhaps earlier still. This applies even to a subject like ventilation.

The Foundations of Hygiene

However the subject of hygiene is taught, the great thing is to implant in the child's mind the all-important fact that the fundamental problem of health is the scientific nurture of the body. The best nurture of the body is simply a question of nutrition, and the elements of nutrition are: (1) food, (2) fresh air and sunlight, (3) bodily exercise, (4) warmth, (5) cleanliness, (6) rest. The loss of any one of these means impairment of health; the neglect of them is an invitation to disease. But they must all be followed in moderation.

Another important thing is to "avoid all stunts and panaceas". Tell the pupils that, if they are ever tempted to take a patent medicine, they should first read the British Medical Association books, *Secret Remedies*, in which they will find the analysis and the cost of all the patent medicines in the market. Why pay three shillings for a bottle of harmless mixture or pellets that can be made up for a penny?

Personal talks to older pupils may take a great variety of useful forms. Amongst suitable topics are the local provision of a sanitary environment—housing, water-supply, drainage and refuse removal, clean streets; infant welfare; child hygiene; a wholesome food-supply; the segregation of infectious persons, disinfection, quarantine; the production of immunity; the provision of anti-toxins; attacks on epidemic diseases; clinics; sanatoria; hospitals; compulsion and education in public health work; preventive medicine. A knowledge of all these things is necessary for the creation of reasoned opinion in the interests of public health; and the Sixth Form boy or girl is easily made a future missionary. Whether the knowledge is given dogmatically or not, the important thing is to provide the knowledge.

Briefly, the laws of hygiene rest on the principles of physics, chemistry, and biology. These principles known, there is little more to be done then to apply them, and, in the application, relatively little experimental work is necessary. If the

preliminary physics, chemistry, and biology have not been done, hygiene should still be taught, but it will fail to make the same appeal, even if experiments are devised to illustrate and to elucidate the points taken up.

CHAPTER XXV

Biological By-ways

Occasional Work for Abler Boys

There is no time in school to wander far away from the beaten track, but the occasional enthusiast of the Sixth Form who leaps ahead of his fellows may be encouraged to read more widely than is demanded by any formal syllabus. Such boys might well be required to read Bell Pettigrew's *Design in Nature* and D'Arcy Thompson's *Growth and Form*, especially if they have a liking for mathematics. (The writer of the first book was, and the writer of the second book is, a distinguished Scottish professor.) The books teem with interest, even for the professional biologist. Professor Pettigrew's book (3 vols.) contains 2000 figures, many of them striking. The collection of facts is remarkable, but the writer's fault was that he was too dogmatic in the expression of his views. Professor D'Arcy Thompson's book (about 800 pages and 400 illustrations) is rather more recent, and is even more remarkable in some ways. The following points, amongst others, might receive attention.

Special Points suggested for Consideration

1. *Structure and Size.*—If two bridges, geometrically similar, are of different sizes, the larger one is the weaker of the two: Why? Nature cannot construct animals beyond a certain size: Why? A man 60 feet tall would crush down with his own weight: Why? Big birds have great difficulty in flying: Why?

In any structure which is enlarged without alteration of

shape, the bulk increases as R^3, but the surface only as R^2. As the bulk of animals becomes greater, it becomes more and more necessary to provide greater and greater absorption surface in the intestines; hence new arrangements have to be made for making the surface more or less proportional to R^3. In many animals the difficulty is surmounted by coiling the intestine; even in man, the intestine is three or four times as long as the whole body.

2. *Animal Locomotion.**—Locomotion on land, in the water, and in the air. How the movements are effected. The wing as a helix. Feather arrangements.

3. *Organic Form.*—(*a*) *Unduloids* and *Catenoids*, and how developed geometrically. Minimal surfaces. Plateau's experiments. Falling drops and splashes, hanging drops, breaking waves. Examples of such shapes in organic cup-like and other creatures, e.g. the *vorticella*, *folliculina*, and some of the *foraminifera*. (*b*) *The logarimithic spiral* mathematically considered, exemplified in various organisms: nautilus, molluscan shells, the successive whorls of spiral shells, the spiral shells of the foraminifera, the horns of sheep and goats, the antlers of deer, the spiral arrangements in nature generally, spiral formations in plants, spiral stems, spiral distribution of leaves and branches, spiral climbing plants. Radiating, concentric, and spiral arrangements common to crystals, plants, and animals. (*c*) *Hexagonal symmetry*. (*d*) *Phyllotaxis*. (*e*) Geometrical forms in corals, pollen-grains, spores, fish scales, scales of butterfly wings, &c.

4. *Comparison of Related Organic Forms* and their geometrical transformations (e.g. skulls), shown graphically by deformations of co-ordinate networks.

5. *Sizes of Organic Forms.*—A typical bacillus is 1 μ in length. One of the smallest known organisms is *M. progrediens*, a pathogenic micrococcus of the rabbit; diameter = ·00015 mm. (= ·15 μ = $1{\cdot}5 \times 10^{-5}$ cm.). Filter-passers are, of course, smaller still.

* In *Nature* for April 7, 1928, there is an interesting article by Mr. A. Mallock, F.R.S., on *Some Modes of Mechanical and Animal Locomotion.*

The *M. progrediens* contain only about 30,000 molecules of albumin, i.e. 30×10^3. Hence an organism only $\frac{1}{10}$ the size would contain only about 30 molecules of albumin. Thus we begin to reach molecular dimensions, and there is apparently a limit to the smallness of organic size. This must be borne in mind when discussing hereditary factors (genes).

CHAPTER XXVI

Astronomy

The Astronomy Usually Taught

As a subject for serious study, astronomy is rarely included in a school science course, one reason being the difficulty of finding practical work of a suitable kind. But all geography courses contain a certain amount of elementary astronomy; for instance:

1. The earth as a globe travelling round the sun and spinning all the time on its own axis inclined $66\frac{1}{2}°$ to the plane of the ecliptic, i.e. the plane of its path round the sun.
2. The consequences of these movements: day and night, the seasons.
3. The moon as a globe spinning on its own axis once a month, and travelling round the earth once a month, in a plane slightly inclined to the plane of the ecliptic. Phases of the moon.
4. Eclipses: comparative rarity of the phenomenon the result of the inclination of the orbits of the earth and moon.
5. Fixing positions on the earth's surface. Latitude and longitude. Elementary notions of map projection.

Older pupils who have done a fair amount of geometry, especially geometry of the sphere, have no difficulty in understanding these things from descriptions and diagrams. But younger pupils require more help, otherwise they cannot visu-

alize the phenomena, they remain puzzled, and their written answers to questions are seldom satisfactory.

If an orrery is available, there is little difficulty, but more often than not, the teacher has to manage with improvised models, perhaps a mounted globe to represent the earth, and painted wooden balls to represent the sun and moon. Personally I prefer to use a large porcelain globe (the kind used with the old-fashioned paraffin lamps) to represent the sun, the globe being fixed in position a foot or so above the centre of the table, and illuminated from the inside by the most powerful electric light available, the room being otherwise in darkness. This makes an admirable sun, and gives a sharply defined shadow. The earth may be represented by a small wooden ball painted white, with a knitting-needle thrust through its centre to represent the axis, and with black circles to represent the equator and the $23\frac{1}{2}°$ and $66\frac{1}{2}°$ parallels, the ball being mounted so that its centre is the same height above the table as is the centre of the sun, and the axis being inclined at $66\frac{1}{2}°$. About one-half the " earth " is now brilliantly illuminated, and the other half is in shade. If the earth is moved round in its orbit, the successive positions of its axis maintaining a constant parallelism, the meaning of (i) day and night and their varying length in different parts of the world, and (ii) the seasons, may be made clear in a few sentences. If more serious work is to be done later, it is particularly necessary that the plane of the ecliptic should be clearly visualized, and this is easily done if the sun and the earth are supposed to be half immersed in water, the surface of the water representing the plane of the ecliptic. Make the pupils see clearly that half the earth's equator is always above, and the other half always below, this plane.

The phases of the moon are best taught by ignoring the model of the earth for the time being and considering models of the sun and moon alone. Let the laboratory sun illuminate a painted ball, to represent the moon; let the pupils move round this ball, from a position where they see the non-illuminated half to the position where they see the fully-illuminated half.

One " phase " after another comes into view, and further teaching is unnecessary. Now put the " earth " in position, and show how the earth may get between the sun and the moon, and prevent the sun from shining on the moon; and how the moon may get between the earth and the sun, and prevent our seeing the sun. And thus we come to eclipses.

The first essential in teaching eclipses is to make pupils realize that a cone of shadow is a thing of three dimensions. Let the school sun cast the shadow of the much smaller school earth. The whole classroom remains brilliantly lighted save for a cone of darkness on the far side of the earth (we ignore all other objects in the room), and the shape and size of this cone is easily demonstrated by holding a screen at varying distances behind the earth. With a second ball to represent the moon, correct notions of total, annular, and partial eclipses may be readily given. It is quite easy to show why eclipses are comparatively rare phenomena by making the moon move round in an orbit inclined to the earth's orbit.

But this is not all. It now remains to represent the sun, moon, and earth in proper proportion and at their proper relative distances. Only in that way are pupils likely to obtain a true sense of things. If the " sun " is 20 inches in diameter, the earth may be represented by a ball $\frac{1}{5}$ inch in diameter, and the moon by another, $\frac{1}{20}$ inch. *It will pay* to take three spheres of these respective sizes (say one of the old-fashioned geography " globes ", a small pea, and a grain of onion seed) and place the two former 20 feet apart, and the two latter 6 inches apart. The true relative sizes and distances always impress the pupils. To cast the actual shadows of such small spheres is in practice impossible, of course, but by a little exaggerated geometry it is easy to show why the moon's shadow which swept across England during the solar eclipse of 1927 was limited in width to about 15 miles. This earlier work must be devised to enable the pupils actually to picture the phenomena fairly accurately. Later work is then comparatively simple.

A More Serious Course of Astronomy

The main interest of astronomers is now concentrated on the stars and the possible organization of the universe as a whole. But in any serious school course of astronomy, at least the introductory work will be confined, in the main, to the solar system. The main topics are therefore likely to be:

1. The sun and moon; their dimensions and distances.
2. The planets and their satellites. Planetary distances.
3. Comets and meteors.
4. The apparent movements of the sun, stars, moon, planets. How we discover the real movements.
5. Stars, nebulæ, the Milky Way: elementary considerations. Names of well-known stars and of easily recognized constellations.
6. The observatory and its instruments. How a combined altazimuth and equatorial may be made for school use.
7. Determination of apparent positions of the heavenly bodies.
8. Determination of real distances and dimensions of the heavenly bodies. Possible deductions when *one* measurement has been determined. Analogy with terrestrial trigonometry. (i) Determination of circumference and diameter of the earth. (ii) Determination of distance of moon.
9. Gravitation and Newton's discovery. Kepler's Laws.
10. True shape of the earth.
11. Greenwich and its time signals. Measurement of time.
12. The nautical almanac: elementary considerations.

Some of these topics are puzzling to many boys. For instance:

1. *Relative Motion.*—Devise means to make the boys see clearly that if they could make their observations from the relatively fixed body of the solar system, viz. the sun, there would be no confusion; that the confusion arises because they make their observations from a body which itself is moving. Show them that the ancients were fully justified in their description of the epicycles, inasmuch as epicycles are exactly what we observe when, forgetting our own motion, we note the planetary paths amongst the stars. (We may make a series of observations and plot a portion of some particular planetary path for ourselves, but the work must extend over a long period.)

Devise a geometrical diagram—or copy one from a standard work on astronomy—to show that a *looped* path of a planet is merely the result of our watching the movements from another planet, which is pursuing a similar motion round the same central body. Another puzzling case is the path of the moon round the earth as the earth moves round the sun.—A pencil stuck at right angles to the edge of a disc (a bread-board, a plate, or the cylinder from the art-room will do), and the disc rolled along the edge of the table which has been pushed up close to the wall, describes on the wall an epicycloidal path. If a circular cardboard disc, 2 or 3 inches greater in diameter than the base of the cylinder, be pinned centrally on the latter, and the pencil be stuck to its edge; and if the cylinder be rolled along the edge of the table so that the projecting edge of the disc is below the table-level, the pencil will trace out a *looped* epicycle on the wall. A similar sort of curve will be traced if the disc and cylinder be made to roll round a fixed cylinder. —Experiments of this kind help greatly to show how the apparent complexity arises in the path traced out in space by members of the solar system. They are more convincing than curves drawn from geometrical data, and take up much less time. Some of the modern astronomy books contain suggestive diagrams, and these perhaps may be used instead. But mere words are useless to make pupils understand the complexity of motions within the solar system.

2. *Celestial Measurements*.—Diameters and distances.—Once pupils realize that this work is very little more than a repetition of what they have done in trigonometry, there is little difficulty. It is generally a question of a base line and the measurement of angles, over again. The principle of determining a circumference of the earth by means of the zenith distances of a selected star from the two ends of a known base-line is easily understood by a Fifth Form boy; so also is the moon's distance by means of (what is practically) the Greenwich-Cape base-line. All other important measurements of the solar system follow on simply, and need take but little time. The main thing is to master main principles.

The pupils must, of course, know something of the geometry of the sphere, and must see clearly the relation of the earth to the celestial sphere. In particular, they must be familiar with (1) the zenith and the horizon, or (2) the celestial pole and celestial equator. Let them understand that the earth's axis would, if extended, pass through the celestial poles, and that the earth's equator extended outward in its own plane would become the celestial equator. Also that, just as positions on the earth are determined by parallels of latitude and meridians of longitude, so positions on the celestial sphere are determined in exactly the same manner. The astronomer calls his parallels, parallels of *declination*, and his meridians, meridians of *right ascension*. Just as we say that our equator has a latitude of 0°, so the astronomer says that the celestial equator passes through all points (on the celestial sphere) of declination 0°. And just as we measure longitude from an arbitrarily chosen point on the equator (the point through which the Greenwich meridian passes and called 0°), so the astronomer measures his right ascension from an arbitrarily chosen point on the celestial equator, the first point of the constellation Aries. In short, we fix positions on the celestial sphere exactly as on the earth.—This *must* be realized geometrically, and a rough model made, say, of wooden hoops will help the pupils much.

A pupil might begin making celestial measurements by using his altazimuth, taking the altitude and azimuth of some selected stars; show him that these measurements are sometimes made in order to define the position of a star in that portion of the celestial sphere we can see above our own horizon. Now show him how to alter his altazimuth so that its telescope is mounted equatorially, and show him how to take the declination and right ascension of the same star, these measurements fixing the position of the star independently of a particular person's horizon.

All those things are the ABC of the whole subject. The celestial sphere and its relation to the earth *must* be visualized and understood before any headway can be made. The pupil

must see that the astronomer and the surveyor are engaged in exactly the same kind of work—they both measure base-lines and angles, they both use telescopes to see distant objects; but the astronomer's base-lines are much longer, his distant objects are very much farther away, and his telescopes are therefore much more powerful.

Let the astronomer's refinements all be postponed until main principles are mastered. In the earlier work, do not trouble to average the distances of circumpolar stars, but look upon *Polaris* as a true polar star; also ignore verniers, refraction, aberration, precession of the equinoxes, obliquity of the ecliptic. Main principles first; refinements later.

Practical Work

What practical work can be done? In day schools, very little, if only because of the difficulty of getting boys back in the evening. Valuable work is possible in a boarding school, and it sometimes happens that a school astronomical society spends more time with the telescope than the school authorities approve. A good telescope is a first essential, and it is a great advantage if this can be mounted as an altazimuth which is convertible into an equatorial (by revolving the base about a horizontal axis). Unless the school is lucky enough to have an observatory, other astronomical instruments are hardly likely to be available, though of course a spectroscope will be part of the physics equipment.

The kind of exercises easily possible are: observations of the moon and the planets, the recognition of the better-known constellations and of the well-known stars, the motion of the stars, the plotting of the moon's path amongst the stars, observations of one or two planetary paths amongst the stars, identification of a few of the great nebulæ, determination of the meridian, determination of the latitude of the place by measuring the altitude of the pole star, simple determinations with the altazimuth and equatorial.

One kind of exercise that always appeals to a boy is this:

the latitude of two places approximately on the same meridian may be taken from an atlas, say, Glasgow and Plymouth, or St. Louis and New Orleans, the distance in miles between the places measured approximately from the atlas, and the circumference of the earth then calculated.

Whatever can be done by observation and experiment to make the astronomy real, should be done.

Sixth Form Work

Certain aspects of astronomy, especially mathematical astronomy (the lunar theory, for instance) are beyond school boys; but there are aspects of present-day research that should be included in any Sixth Form course.

This, in the main, is work in astrophysics, a region in which astronomy and physics overlap. Astrophysics may be regarded as the study of the light received from the celestial bodies, and of the consequential problems concerning the constitution and inter-relations of those bodies. The chief instruments used are the telescope, the spectroscope, the camera, and the interferometer. By long exposure, the camera can photograph objects too faintly illuminated to impress a plate in a short time; and, more than this, a photographic plate is sensitive to ultra-violet light which the eye cannot see. Since many of the new important spectra lie in the ultra-violet region, the interpretation of such spectra is almost entirely an affair of interpreting photographs. But this class of photography is of much too expert a character to be attempted in schools, and of course no school is likely to be equipped with an interferometer (an instrument for the direct determination of stellar distances).

School work will probably be confined to the full understanding of the working of the spectroscope, to consideration of the data which astronomers have obtained, and to the inferences that may be drawn from such data. We summarize a possible course.—It is assumed that a course of light has already been done, also that the pupils have an elementary knowledge of the spectroscope.

1. *The Spectroscope:*

(1) Its original use in chemical analysis. How it now provides us with a great wealth of physical data. How the spectroscope is influenced by changes in the chemical and physical condition of the object observed.

(2) The two methods of analysis: (*a*) by glass prism, (*b*) by diffraction grating. Explanation, and elementary theory.

(3) Three standard methods of exciting a substance to radiate its energy: (α) *flame*, (β) *arc*, (γ) *spark*. The enhanced lines of a spark spectrum and what they signify.

(4) Emission and absorption spectra: the essential difference.

(5) Continuous, line, and band spectra, and how they are produced.

(6) How and when a luminous vapour may give its spectrum either as light emission lines on a dark background, or as dark emission lines, in the same position, on a bright background.

(7) Why luminous solids and liquids emit continuous spectra.

(8) The remarkable regularity of spectrum lines, even when they appear to be hopelessly chaotic.

2. *The Principle of Spectrum Analysis.*—The wave-lengths of the spectrum lines produced by an unknown substance are measured, and are then compared with tables giving the wave-lengths of lines corresponding to the different chemical elements; the identification is then made.

The direct measurement of wave-lengths is a very laborious matter. Standard wave-lengths have been measured with very great accuracy, especially the numerous lines of the iron arc spectrum; and the wave-lengths of unknown lines are calculated from the position of the lines with respect to the standard. Show how, in practice, the iron arc and the

unknown substance are exposed to different portions of the slit, and how the rows of lines are thus compared.

3. *Displacement of Spectrum Lines:* the causes.

4. *Radiation.*—This is *the* question of modern spectroscopy and astrophysics: what is actually taking place in the radiating body that results in the spectrum we see? Hypothesis: the smaller the orbit in which an electron revolves, the smaller the amount of energy possessed by the atom, so that, in the normal state, the atom has its minimum energy. The exciting agency, therefore, in removing the electron to a distant orbit, adds energy to the atom, and when the electron returns, the atom must give up some or all of this energy, according to the particular inner orbit in which the electron now revolves. It is precisely *the energy which the atom thus yields up that is held to account for radiation.* It is radiated in the form of an ætherial wave of a certain definite frequency. (See Chapter XXXI.)

5. *Wave-lengths and Frequencies.*—Special units are employed, inasmuch as the magnitudes are so entirely different from those with which we are familiar, and it is therefore desirable to deal with figures of reasonable dimensions.

(i) *Wave-length unit* $= 10^{-10}$ metre
$=$ 1 "tenth-metre" or "ÅNGSTRÖM UNIT (A.U.)."

(ii) *Frequency*: not usually indicated by the number of waves sent out per second, but by *the number of waves contained in one centimetre of the wave-train*; this

$$= \frac{\text{true frequency}}{\text{velocity of light}} = \textbf{wave number.}$$

Let the pupils apply this principle to a particular instance, and let them memorize both the principle and the instance.—Consider the wave-length of, say, a particular green colour, measured and found to be 0·0000005 metre.

$$\textbf{Wave-length} = 0{\cdot}0000005 \text{ metre} = \mathbf{5000\ A.U.}$$

$$\textbf{Frequency} = \frac{\text{velocity of light}}{\text{wave-length in metres}} = \frac{3 \times 10^8 \text{ (metres per second}}{0{\cdot}0000005}$$

$$= \mathbf{6 \times 10^{14}} \textbf{ waves per second.}$$

Hence,

$$\textbf{wave-number} \left(= \frac{\text{true frequency}}{\text{velocity of light}}\right) = \frac{6 \times 10^{14}}{3 \times 10^8 \times 10^2}$$

$$= \mathbf{20{,}000}.$$

Thus the particular radiation has:

(i) a **wave-length** of **5000 A.U.** (usually written λ**5000 A.U.**).
(ii) a **wave-number** of **20,000** (usually written ν**20,000**).

Visible light extends from about λ7600 in the red to λ3900 in the violet.

6. *Solar Spectra.*—Photographs and how they are interpreted.

7. *Stellar Spectra.*—Their interpretation. Questions to be answered: what physical conditions give rise to the spectra of the stars? and how are these conditions related to other stellar qualities?—Some idea of the way in which stellar *magnitudes*, *movements*, *velocities*, *distances*, *temperatures*, and *colours* are inferred.

Topics for Lectures

In school astronomy, there are certain topics which are best treated frankly as lectures. They concern the results of recent research. The results are easily described, and much of the supporting evidence may easily be understood by Sixth Form boys.—All through the lectures, facts should be carefully distinguished from hypotheses, and an endeavour should be made to indicate the degree of probability of the truth of each hypothesis, according to the extent and nature of the evidence on which the hypothesis rests.

1. *The Stellar System.*—Number of stars: 5000 visible to

naked eye, 100,000 in a 1-inch telescope; perhaps about 1,500,000,000 in all. Our sun not far from centre of stellar system. System apparently finite: its general shape. Stellar distances: nearest star is Prox. Centauri, (24×10^{12}) miles distant; then α Centauri, (25×10^{12}) miles; then Lalande, (47×10^{12}). Sirius, the brightest star in the sky, is (50×10^{12}) miles away. There is a steady succession of objects until 20,000 times the distance of Sirius is reached. One known star-cluster is (6×10^{18}) miles distant.

It is useful to convert these vast distances into light years. Light travels at 186,000 miles a second, i.e. at 6 billion (6×10^{12}) miles a year; this distance, (6×10^{12}) miles, is called a light year. Thus the nearest star is about 4 light years distant, and some of the remoter nebulæ may be a million light years (6×10^{18} miles) distant.

Stars do not interfere with one another much. Each has as much space to move about in as one tiny midge would have in the largest hall in the world. We do not know how many extinct (dark) stars exist, but dynamics suggest not more than ten times the number of luminous stars. Estimated that a star would suffer collision only once in 10^{14} years.

Stellar system recognized as one vast organization, pointing to a common origin of large groups of stars; for instance, the bright stars of Orion have a common motion; so have the Hyades.

2. *Size of Stars.*—In 1920, Michelson measured the angular diameter of Betelgeuse (the first time a star was thus measured), a 20-foot interferometer being used. The star had a disc $\frac{1}{20}$ of a second of arc in diameter, the size of a halfpenny fifty miles away. The distance being approximately known, this apparent size can be converted into approximately the actual size. Diameter = 200,000,000 miles.

The older method of estimating the sizes of stars:—From our knowledge of a star's surface temperature, its radiation *per square inch of surface* may be calculated; from the star's distance and apparent brightness, the radiation *of the whole surface*

may be estimated. Simple division gives the area of the surface. The later interferometer method gives results almost in exact agreement with the older method.

By volume, 1,000,000 earths = 1 sun.
10,000,000 suns = 1 Betelgeuse.

But Betelgeuse has a mass of only about fifty times that of the sun; its vast bulk is due to the extreme diffuseness of its material. The matter constituting the universe has aggregated primarily into units of approximately equal masses. With few exceptions, they range from $\frac{1}{2}$ to 5 times the mass of the sun. The smallest known star is roughly the size of the earth.

3. *The Nebulæ.*—The great spiral and other extra-galactic nebulæ: consider these either as a family of stars, or of stars in the making, or as matter ultimately destined to form stars. Mass of each great nebula estimated to be equal to 10^9 suns, but mass is so tenuous that each millionth part of an ounce has, on the average, a volume of several cubic miles. (The calculation is 10^{-16} gm. per cubic centimetre. The small amount of gas in an ordinary electric light bulb, if spread through a great hall like Olympia, would still be about 10,000 times as dense as the nucleus of a spiral nebula.)

Estimated that about 2,000,000 great nebulæ are visible in the great 100-inch telescope on Mt. Wilson. But only a comparatively small fraction of the whole universe is visible in this telescope, viz. about 10^{-9}. Hence the possible number of stars in the making is

$$10^9 \times 2.10^6 \times 10^9 = 2 \times 10^{24}.$$

4. *Temperature and Energy of the Stars.*—We know from the nature of the light received from Betelgeuse that the surface temperature is 3000° C. But this gives us no idea of the great heat within.

The greater the heat of a gas, the greater its expansive force. At any point inside a star, a certain condition of balance must be reached. On the one hand, we have the *weight* of all

the layers above pressing down on the gas inside. On the other hand, we have the *elasticity* of this inside gas trying to expand and force the upper layers outward. Since neither the one thing nor the other happens, the two tendencies must just balance. *At each point the elasticity, and therefore the heat, has to be of the exact amount needed to bear the weight of the layers above.* That is the principal clue by which it is determined how much heat there must be at various depths inside the star. The internal temperature depends on the particular star, but at the centre it is generally from 2 to 20 million degrees. This is not a temperature so vast that our ordinary ideas of temperature break down. Temperature is a mode of describing the speed of motion of the ultimate particles of the matter. In a mass of helium at ordinary temperatures, the average speed of the atom is rather less than a mile a second; at 4,000,000° it is 100 miles a second.

A typical giant star must be conceived as a mass of material with an average density of about that of air, equal in volume to at least 1000 times the volume of the sun. The atoms of which it is composed are rushing in all directions, up to a speed of 100 miles a second. The atomic energy constitutes a great store of heat contained in the star. But the star contains a further store of heat, ætherial heat or æther waves encaged by the material. In giant stars the heat is roughly equally divided between the two forms.

A beam of light or æther waves exerts a pressure, just as a jet of water or a wind does (this is because it carries mass with it), a very minute pressure as a rule. But the intense ætherial energy inside a star makes a strong wind and exerts a great pressure. This wind-like pressure distends the star. To some extent it bears the weight of the layers above, leaving less for the elasticity of the inner gas to bear. The ætherial wind-pressure and the material elasticity together share the burden of supporting the weight of the layers above. The ratio in which they share it depends on the whole *mass* of the star, not on the density or on the chemical composition of the material.

Astronomers are able to estimate this ratio, and here is a summary of the results: "For globes up to 10^{32} grs., the material pressure is far greater than the ætherial. In globes of 10^{33}, 10^{34}, and 10^{35} grs., the ætherial pressure begins to be an important factor in the situation. In globes of 10^{36} grs. and above, the ætherial pressure is far greater than the material. The thousand million globes of gas in the skies are all of mass between 10^{33} and 10^{35}. The lightest known star comes just below 10^{33}, the heaviest just beyond 10^{35}."

"Were gravitation unresisted, it would build globes of enormous size. But ætherial pressure is a disruptive force (doubtlessly helped by the 'centrifugal' force of the star's rotation), and it prevents the accumulation of large masses. The ætherial pressure brings the accumulation to a halt as soon as 10^{35} grs. is reached, because by then it has become just powerful enough to master its opponent."

"As a gaseous star contracts, its temperature rises. Betelgeuse is typical of the first stage where the temperature has risen just far enough for the star to be luminous. It will go on contracting and becoming hotter, its light changing from red to yellow and then to white. When the condensation has proceeded far enough, the material will be too dense to follow the laws of a perfect gas. The rise of temperature then becomes less rapid, is checked, and finally falls. We can calculate that the greatest temperature is reached at a density of about $\frac{1}{4}$ to $\frac{1}{3}$ that of water. The sun is denser than water, so that it has passed the summit and is in the stage of falling temperature. As long as the temperature is rising, the brightness of the star scarcely changes; it is becoming hotter, but smaller. But on the downward path the light falls off rapidly, because of the falling temperature and diminishing surface. Through any given level of temperature, a star passes twice, once ascending, and once descending. The condensation of Betelgeuse will continue, and, perhaps after some billions of years, the star will become small and dense like the sun."

"A star contains within itself energy to last the rest of its life. The greater part of the store of energy is energy of con-

stitution of the atom and its electrons, i.e. sub-atomic energy. This store of energy inherent in the constitution of the electrons and protons cannot be set free unless the containing atoms are annihilated."

" Probably the matter of the star's hot central regions consists of a mixture of bare nuclei and free electrons. As we pass outwards towards the star's surface the temperature falls, and we come to atoms which are more or less fully formed, until finally, close to the surface, we meet with atoms fully formed."

The spectroscope shows what elements are in the stellar surface. When the spectroscope is turned on Sirius, we see hydrogen and very little else. We do not on that account think that Sirius is made chiefly of hydrogen, but that its surface temperature is 10,000° C., because that is the temperature specially favourable for the hydrogen to show itself.

There are three methods of estimating the ages of stars, and they lead to much the same results. The age is generally from 5 to 10 billion (5×10^{12} to 10×10^{12}) years: this number is the *general* order of the magnitude of the age.

5. *Birth of Stars.*—Stars almost certainly had their origin in nebulæ. Nebulæ are huge masses of gas endowed with different amounts of rotation. Such a mass of gas not rotating would assume the shape of a sphere; rotating, it would become an oblate spheroid, and ultimately a disc-like structure. Examined spectroscopically, the nebulæ are found to be rotating with high velocities about an axis which appears in the sky as the shortest diameter of the nebula.

Mathematical theory shows that the cooling of such a rotatory flat oblate spheroid must cause it to condense and throw off detached portions. Nebular photographs actually show this in progress. Moreover the calculated estimates of the masses of the detached portions come out to just about the same as the masses of the stars.

If a nebula is in rotation, its angular momentum must remain constant, and the shrunken mass can carry its original dose of angular momentum only by rotating more rapidly

than before, the effect of shrinkage being adjusted by change of shape. Further shrinkage leads to the breaking up of the nebula, matter being thrown off from the equatorial region.

6. *Birth of the Solar System.*—Laplace's hypothesis fails; it does not stand mathematical investigation. If we work backwards from the present amount of spin in the system, calculation shows that the sun could never have had sufficient spin for bodies to separate from it.—At the moment Chamberlin's hypothesis holds the field. Two stars may collide, though this must be very rare. Two may just escape colliding, huge tides are raised, and these may take the form of long streamers of gas. These streamers may issue with such velocity that they may break away, just as if huge bolts were shot forth from the sun. Quite probably the planets were formed in this way. But such close approach must be rare. Calculation shows that, even after billions of years, only about one star in 100,000 can be surrounded by planets born in this way. In the 10^9 stars in the visible universe, there are probably not more than 10,000 planetary systems. There is perhaps one birth every 10^9 years.—Contrast the birth of the solar system with the birth of the stars.

7. *The Sun.*—The sun radiates enough energy from each square inch of its surface to keep a 50-h.p. engine continually in action. Still hotter stars may radiate as much as 30,000 h.p. per square inch. A searchlight which is radiating 50 h.p. of energy is discharging with the radiation into space *mass* at the rate of 1¼ *grams a century.* The sun's surface is so large that the sun as a whole is discharging mass at the rate of 250,000,000 *tons a minute.* Now the sun has no source of replenishment. It must have weighed 360,000,000,000 tons more yesterday than to-day. We can calculate that 5 or 10 billion years ago, the sun must have been several times as massive as it is to-day. Thus young stars are probably many times as massive as old stars. The radiation which has been produced continuously for billions of years must, presumably, have been due to the annihilation of electrons and protons.

The surface temperature of the sun is about 6000° C. When the sun was in its prime, that temperature was probably 6600° C.; it has not mass enough for the temperature to be much higher.

The age of the sun is perhaps 10^{10} years, perhaps half as much again. The mass of the sun is 2×10^{27} tons.

A billion (10^{12}) years hence, the sun will probably be much as now, with the earth revolving round it much as now. The year will be a little longer, and the climate considerably colder.

8. *Eclipse Prediction.*—The discoveries of the ancient astronomers. The Saros and its factors. Modern accuracy of prediction, and why more so than in ancient times.

9. *Newton.*—The full story of his discovery of the law of gravitation.

10. *Short History of Astronomy.*—The pioneers. Present-day workers.

11. *The Calendar.*—A fixed Easter? Advantages. Objections mostly of a sentimental kind. The more general reform of the calendar; the present illogical calendar division indefensible. Daylight saving.

Throughout these lectures, the teacher should emphasize the fact that most of our knowledge of the stellar system is merely inferential, even speculative. The interpretation of the available spectroscopic data is largely hypothetical, though our leading astronomers do, it is true, agree about main conclusions. It seems *probable* that the main hypotheses are in harmony with the facts, but we cannot say more than this.

Books

Do not despise some of the older works. The names of Herschel, Ball, Lockyer, Proctor, and others are proverbial for their lucid

explanation of difficulties in connexion with the solar system. Let every boy read Sir R. Gregory's *The Vault of Heaven*; it is a most teacher-like book. This might be followed by *Astronomy with the naked eye*. For Astrophysics, consult H. Dingle's *Modern Astrophysics*. For recent work, see Professor Eddington's *Internal Constitution of the Stars*, and Sir James Jeans's books.

CHAPTER XXVII

Science in Rural Schools

The Kind of Work that is Advisable

Farmers have little confidence in school courses of agriculture, contending, possibly justly, that science teachers cannot have an inner knowledge of agricultural practice. And in order that boys may be induced to take an interest in rural life, it is no longer considered necessary to make agriculture a subject of school instruction. Scientific agriculture is now systematically taught at the agricultural colleges and farm institutes where there are naturally much great facilities than can be provided in schools.

But a course of instruction with a definitely rural bias is a different thing. The term " rural bias " connotes such modifications of the commonly accepted scheme of work in science, mathematics, and manual instruction as are necessary to make these subjects suitable for rural schools. Although such modified science courses, like all school science courses, must be laid upon foundations of physics and chemistry, it is the study of plant and animal life, and the relation of these to the soil and to the atmosphere, that are the main things to be kept in view. Experiments in the garden as well as in the laboratory must receive special attention. Such a course should not be a feeble copy of a course at an agricultural college; primarily it will be educational and not technical. Technical matters of purely professional interest to the future farmer will be omitted. The breeding and manage-

ment of stock and the diseases of stock, for instance, are subjects unsuitable for school work; so are such crafts as farriery and hedging; so are butter-making and cheese-making.

The subject of agriculture is so large and touches upon so many branches of knowledge that, even at an agricultural college, selection becomes imperative; otherwise, there will be too little training in observation and experiment, and too much compiling of encyclopædic note-books on farming. In drafting a school science course with a rural bias, a teacher must be ruthless in cutting out all topics which either do not lend themselves readily to observational and experimental work or are unrelated to general principles.

The course must provide a training as exacting as courses of the more severely academic kind. The training must be such as to equip a boy, who is to enter upon an agricultural course at the university or agricultural college, in such a way as to make it unnecessary for him to spend much time there in learning " pure " science: it is assumed that such boys will spend at least one year in the Sixth Form. But the training must also provide adequately for the boy who at 16 or 17 goes back to his father's farm, by which time he should be able to grasp the content of a book on agricultural chemistry and kindred subjects and so continue a self-education on technical lines. And both classes of boys should be encouraged to aim at fitting up, on the farm they some day hope to run, a well-equipped chemical and biological laboratory.

Drawing Up a Course: Some Principles

A clear understanding of the processes of plant and animal life, and of soil cultivation, depends upon a knowledge of the fundamentals of physics, chemistry, and biology. The first thing to do is to map out a course in these three subjects, bearing in mind all along, when establishing principles, the possible applications and illustrations that may be drawn from rural life, though the bare bones of the three subjects will be almost identical with those in any other science course. For

instance: phosphorus and phosphoric acid will be included in the chemistry course because they are required for the study of phosphatic manures; carbohydrates and fats will be included in the chemistry course because they are necessary for explaining feeding values; osmosis will be included in the physics course in order to illustrate (amongst many other things), the danger of applying large dressings of nitrate of soda; the general characters of gramineous plants will be included in the botany course, in order that the lessons learnt may be afterwards applied to the special characters of wheat, oats, barley, &c. And so generally. Jot down the hundred and one things the future farmer ought to know; sort out the underlying principles of physics, chemistry, and biology, and classify them; then fill in gaps in order to frame rationally developed courses in the three science subjects. These courses should be so designed as both to afford a rigorous training in scientific method and to provide the scientific facts and principles wherewith to explain and illustrate processes in farming operations. It is these processes that give a *bias* to the course. Some more complex process may touch upon more than one of the three main subjects; for instance, the principle of the rotation of crops has relation to (i) the distribution of root-systems; (ii) the selective power of the plant in regard to substances in solution; (iii) the nitrogen cycle. Clearly the appropriate selection of topics is of fundamental importance for teaching purposes.

Suggested Outline Courses

PHYSICS.—Densities. Fluid pressure. Osmosis (elementary treatment, but thorough). Soil physics (highly important). Surface tension (elementary) and capillarity. Elementary heat. The steam-engine and the internal-combustion engine. The visible and invisible spectrum. The electric current and electric supply (of coming importance in rural districts).

MECHANICS.—Elementary principles, illustrated by machines (only elementary mathematical treatment necessary). Levers, pulley-blocks, screw-jacks, trains of wheels, belts and shafting,

simple roof-structures, and so on, bearing in mind farm out-buildings, and the mechanical devices employed in farm implements. The mechanism of the steam-engine and the internal-combustion engine.

CHEMISTRY.—Qualitative and quantitative study of air and water. Combustion; oxides; acids, bases, salts. S, H_2SO_4, the sulphates. Cl, NaCl, HCl, the chlorides. N, NH_3, HNO_3, the nitrates; putrefaction and nitrification. P, H_3PO_4, the phosphates. Silica, sand, clay. Carbon and its oxides. Carbonates and hardness of water. (See Dymond's book.)

Compounds that are of interest to only the professional chemist should not be included. Something of the nature of such bodies as alcohol, fat, glycerine, soap, sugar, starch, and carbolic acid should be known, and therefore a brief course of organic work is desirable. Include also such chemical facts and processes as may have any sort of bearing on agricultural practice or are of agricultural significance. The chemistry course should be carried far enough to enable the pupils to understand the laws of chemical combination and the meaning of a chemical equation. The chemical analysis of the soil must be reserved for Form VI, though the estimation of the amount of water, soluble matter, and humus in the soil may be undertaken by pupils in IV and V. The practical work may well lean a little in the direction of analysis, qualitative and quantitative (gravimetric and volumetric in VI). The preparation of a few typical salts should be included in the course, and the younger pupils might be given a special course on solubility and crystallization.

BIOLOGY.—(i) *Botany*. Morphology and classification should receive some attention, but function should stand first: transpiration, respiration, root-pressure and osmosis, photosynthesis. Culture solutions. The life of flowering plants, including grasses, and the function of their vegetation and reproductive organs, based on a study of familiar types. Germination (may be hastened in winter by keeping an incandescent lamp about 2 inches above the seeds, the seeds being just covered with wet saw-dust). Vegetative reproduction — cuttings, layers,

budding, grafting. Pollination. The study of a few orders of economic importance: *Gramineæ*—true grasses and cereals; common grasses on the farm; *Cruciferæ*—cabbage, turnips, swedes; *Rosaceæ*—plums, cherries, apples, pears; *Leguminosæ*—beans, peas, vetches; *Umbelliferæ*—carrots, parsnips. Weeds on the farm; injurious effects; habits; extermination.

(ii) *Zoology*. Some common small animal (say rabbit) should be dissected, its organs identified, and its general physiology understood. There should also be a practical study of the metamorphosis of the frog and a few common insects (say, bee, beetle, moth, daddy-long-legs, dragon-fly, water-boatman). Outlines of the classification of animals. Observations of local wild animals, birds, and insects; their haunts and ways. Farmers' pests and preventive measures.

Out-of-door Practical Work

Plot for Seed Experiments.—Sow seed (1) at different depths; (2) at different dates; (3) of different sizes; (4) thickly and thinly; (5) in fine and in coarse tilth; (6) in varying degrees of dryness. Thinning at various stages of growth.—Of course the seed must be sown by hand, and to that extent is not practical farming.

Cultivation.—Shallow and deep digging; trenching; influence of these in first and successive seasons. Raking and compressing the soil surface; harrowing and rolling. Influence of different kinds of manures on plant growth.

Five Small Plots.—To show the effect of no manure, no nitrogen, no phosphate, no potash, a complete manure (on such typical crops as barley, clover, cabbage, beet, mangels, grass).

Comparative Studies.—Sow the winter bean, the Windsor bean, the garden pea, the sweet pea, the everlasting pea, the scarlet runner, the French bean, and the garden lupin. Note differences in morphology of root, stem, leaf, flower; in methods of climbing, methods of pollination, the turning down of pollinated flowers, methods of seed dispersal.

Order Plots.—For gramineæ, cruciferæ, rosaceæ, leguminosæ, umbelliferæ.

Fruit Plots and Rose Plots.—These should be large enough for permanent bush-trees of apples and pears, gooseberry bushes, red and black currant bushes, and a variety of bush roses. Propagation work—seedlings, cuttings, layering, budding, grafting. Plant fruit tree and rose stocks; raise paradise cuttings for apple stocks; and brier cuttings for rose stocks. Pruning: the development of dormant buds; influencing the shape of a tree. Insecticide and fungicide washes.

All this outside work should be essentially of an experimental character, supplementing the work of the laboratory. *It should not be looked on as mere gardening.* The work should not only encourage an open mind, but encourage a reluctance to follow blindly an established practice.

Other Supplementary and Complementary Work

Border-line subjects, associated with mathematics, mechanics, mechanical drawing, and manual instruction:

1. Plans, elevations, and construction of farm buildings.
2. Construction of different kinds of fences.
3. Farm machinery and implements, and their construction.
4. Farm drainage and water supply.
5. Chain surveying; levelling (at least as far as is necessitated by a drainage system).
6. The cubical content of stacks.
7. Manual work: construction (in the school workshops) of a garden gate, a five-bar gate, wheelbarrow, roof-truss, drinking-trough, stile, ladder, &c.; hinges, stays, staples, latches, linch-pins, &c. Simple plumbing, e.g. the making of lead gutters. Use of galvanized iron. Repairs to broken implements. Different kinds of timber. Common building materials, nature and uses.

Every farmer ought to be able to judge intelligently, if not actually to make, the implements and structures pertaining to the farm.

Sixth Form Work

All branches of the subject may be carried by a Sixth Form to a higher standard. In particular, much more advanced chemistry may be done. It might include the special study of the important bases and acids of common occurrence in soils and manures, and the organic compounds in feeding-stuffs.

The abler boys might try agricultural experiments, say on crop production. Some remarkable experiments on wheat production were carried out at Oundle in 1910–1. Teachers interested in this kind of work might make inquiries about present-day work there. The Head Master of Dauntsey Agricultural School should also be consulted. And there is always Rothamsted willing, even anxious, to advise.

Books for Reference

See the Science Masters' Association Library Catalogue. The Board of Education have issued special Reports on Rural School work, and these should be consulted. Mr. Dymond's *Chemistry for Agricultural Students* and Percival's *Agricultural Botany* should be read by all Rural School Science teachers.

CHAPTER XXVIII

Domestic Science

"Science" or "Craft"?

"Domestic science" is a term sometimes given to housecraft as an art, sometimes to a sort of pseudo-science supposed to supplement the craft work, especially on the food side. The work done has rarely much claim to rank as "science", in the correct sense of the term.

A domestic science course sometimes begins in much the same way as courses in elementary physics and chemistry, and then suddenly and much too soon launches off into what

purports to be organic and physiological chemistry, without establishing any real connexion with the work already done. The books used are too often mere small encyclopædias of useful knowledge. The true aim of science teaching is missed. No definite body of general doctrine is built up. Principles may be laid down, but they are too often laid down on a basis of insufficient evidence. The work is too superficial, and the preliminary grounding is altogether insufficient. It is not realized, for instance, that even the simple study of carbohydrates and fats presupposes a preliminary training in elementary organic chemistry, much more than is usually attempted; and that the study of proteins demands a grounding in organic chemistry that is seldom possible in girls' schools.

The question is sometimes asked, Is it of any use even to attempt to give school housecraft a scientific basis? Is a woman likely to make a better cook because she knows the chemical reactions of baking-powder? or is she likely to select and cook a joint better because she knows that the protein in the meat is myosin? It will not be denied that if a better practical cook is the desired end, one lesson in the kitchen is worth two in the laboratory. Moreover, a laboratory course which consists of just a succession of useful little experiments, scarcely related and not associated, may teach useful facts, but it cannot provide that particular form of exacting training which is the special function of a *science* course.

Admittedly every intelligent woman who runs a house ought to know the *rationale* of most of the processes and happenings in her daily environment. For instance, in *mechanics and mechanism*, the reading of meters, the regulation of clocks, the uses of lubricants, the mechanism of the knife-machine, the vacuum cleaner, the sewing-machine, and the bicycle-pump, taps and cisterns, drains and traps, the capacity of different vessels (tea-spoon, table-spoon, wine-glass, &c.); in *heat and heating*, thermometers, fixed stoppers, kitchen-ranges, hot-water systems, the thermos flask, burst pipes, freezing-mixtures and ice creams, damp clothing, fabrics, the bronchitis kettle, steam scalds, the relative heat values of coal, coke, gas, oil,

and electricity, ventilation; in *lighting*, oil, gas, and elec.ric lighting, management of burners, mantles, lamps, switc.ies, fuses.

With such topics as these before her, the responsible mistress may formulate a syllabus of instruction in physics, ' ling in gaps to give the course a rational sequence. The main ject would be to give a clear understanding of principles. The house problems would then no longer be rule-of-thumb affairs but applications of known principles of science.

In the strictly educational sense, however, science often plays but a humble part in this kind of work. Let us consider a particular phenomenon, say that of a " burst " kitchen boiler. The ordinary housewife will not improbably have been told during her domestic science course that cold water admitted to a dry red-hot boiler causes the boiler to " burst ". True she has learnt a useful fact, namely, that cold water must *not* be admitted to a dry red-hot boiler. But when she states that the boiler will " burst ", she states a common fallacy, and shows that her training in elementary science has not been serious. With clear notions of latent heat and calorimetry, she would know that the result would be only a fracture, and not even that if the plates were of steel. This does not mean that she should necessarily have worked numerous quantitative experiments in calorimetry, but she should have done enough to know that the amount of heat stored away in the red-hot plates is altogether insufficient to convert more than a very small quantity of the inflowing cold water into steam, and that the resulting steam pressure will be relatively negligible. She ought to have learnt that the danger of a burst can arise only when the return or vent pipe is blocked up, that then the pressure in the system brings about a high temperature, and a fracture leads to an immediate conversion of the whole of the water into steam.—The properly trained pupil will have learnt all this from her earlier course on heat. The cook-book-recipe-supplied housewife will think in terms of a big bang, a nasty mess, and possible personal danger; she will certainly not think scientifically.

Cleaning Agents and Operations

There are, however, parts of the usual housecraft course that lend themselves to a fairly satisfactory treatment. The subject of cleaning operations is one. Although this subject is so varied that it cannot be cast into the form of an entirely satisfactory scheme of science instruction, its parts may yet be classified and dealt with in a reasonably intelligent manner.

General principles: e.g.:

1. The close relationship between dirt and disease.
2. A cleaning operation may consist of two distinct processes; for instance:
   (*a*) The breaking up of a greasy deposit;
   (*b*) The removal by mechanical means of the dust now set free.
3. Choice of a suitable solvent, e.g. one that will dissolve or unite with grease without injuring the material.
4. Choice of a suitable cleansing agent in order that the " finish " of the article operated on may not be impaired.
5. Distinction between surface dirt (e.g. on wood or wallpaper) and dirt settled amongst the fibres of fabrics.
6. The necessity for preserving the colour as well as the texture of materials.
7. The limitations of cleansing agents.

Preliminary classification of things to be cleaned.

1. Fabrics, furs, feathers, gloves, hats, &c.
2. Paper, parchment, vellum, prints, pictures.
3. Linoleum, oil-cloth, carpets, rugs, skins; leather.
4. Wood-furniture—painted, stained, polished, &c.
5. Marble, stone, plaster, alabaster, porcelain, glass (mirrors, windows, decanters, &c.).
6. Metals: brass, copper, burnished steel, soft metals (tin, zinc, &c.), silver-ware; stoves, metal bath-tubs, metal lamps, &c.
7. " Paint ", e.g. doors, window-frames, &c.
8. Various, e.g. sponge; ivory, bone, and composition articles.

Preliminary classification of stains, tarnishes, &c.

1. Dust—free, and fixed by films of grease, &c. The nature and origin of dust.
2. Soot and smoky deposits.

3. Grease, oil and wax; stains and deposits.

4. Fruit stains on metals and fabrics, food stains, tea and coffee stains, wine stains.

5. Medicine stains; blood stains.

6. Ink stains: black ink, red ink, aniline ink, printer's ink. Iron stains and rust spots.

7. Acid stains: stains from alkalis.

8. Pitch, tar, paint: on clothing and on the hands.

9. The white mark on a polished table, e.g. from a hot dish.

10. The tarnish on metals. Oxides: how they are alike and how they differ.

11. Mildew: how it differs from a stain.

Cleansing agents: their nature. Classification and comparative study.

1. Fresh air and sunlight: their action. The use of a damp cloth. " Shaking."

2. Water: cold, warm, and boiling. Comparative study of these as cleansing agents. Effects of boiling water on fabrics, e.g. woollen goods and prints; any injurious effects?

3. Action of dry heat: e.g. the use of a hot iron held over a spot of grease or wax?

4. Soaps: comparison of their detergent properties.

5. Alkaline solutions: AmHO, NaHO, KHO; comparative study. Cold and hot solutions of washing-soda. Soap-powders. Saponification; emulsions.

6. Comparative study of citric acid (including the cut surface of lemons), tartaric acid (cold and hot solutions), oxalic acid, acetic acid, hydrochloric acid.

7. Naphtha, turpentine, alcohol, ether, benzine, petrol; comparative study of their solvent properties; the dangerous nature of the last three: warnings.

8. Ashes, emery, powdered pumice, rottenstone (and oil), powdered chalk, whiting.

9. Bran (and hot bran, for feathers), meal, saw-dust, starch (including paste of cold-water starch). French chalk. Fuller's earth. The special work of absorbents.

10. Bleaching powder, sulphur dioxide, and perhaps hydrogen dioxide.

11. Brass polish, globe polish, " monkey soap ", furniture polish, plate powder, &c. Composition of polishes; hence their probable action.

12. Various agents: e.g. bread crumbs; skim milk, buttermilk; ox-gall; borax. boracic acid; glycerine; " florigene ", &c.

Systematic study of cleaning, reduced as far as possible to simple experimental problems of investigation. For instance:

1. The need of softening pitch or tar with grease or oil before applying turpentine or alcohol.

2. The difficulty of removing ink stains because of the uncertainty of the composition of the ink. Successive applications of cold water, tepid water, skim milk, oxalic acid. The advantage of attacking an ink stain at once—say by sprinkling with salt and rubbing with lemon pulp. Action here?

3. The nature of mildew. Simple remedies for removal; the probable effect of the more drastic remedies.

4. If acid dropped on clothing, why immediately apply an alkali? When acids are used for cleansing purposes, why follow up with alkalis and then hot water? If strong alkalis used, why follow up with acids? Are strong acids desirable?

5. Marking-ink stains. The composition of the ink; hence method of attack.

6. The nature of bleaching, and the study of chloride of lime. The possible destruction of the fibres and of the colours. Can this be avoided? Sulphur dioxide as an alternative; when it should be used.

7. Comparative study of turpentine, benzine, ether, and petrol for taking grease out of coarse and out of delicate fabrics. The danger of using these agents; warn again.

8. The study of alcohol as a solvent. Hence the action of brandy, whisky, perfume, &c., if spilled on a polished table. Remedy?

9. The use of vaseline for preventing polished metals from rusting.

10. Vacuum cleaning; action? "Dry" cleaning; action?

The work of the laundry.—Revision of work already done.

1. Hard and soft water; how to soften water.

2. Soaps and soap substitutes. Washing-soda, ammonia, borax, and other materials used in the laundry. Their action and use.

3. The general study of alkalis as used in the laundry.

4. Bleaching and bleaching agents. The use of blue.

5. Stiffening agents.

6. The various processes of the laundry classified and analysed according to the scientific principles underlying them.

The household laboratory.

1. Supplies of benzine, turpentine, ox-gall, tartaric acid, oxalic acid, hydrochloric acid, chloride of lime, ammonia, caustic soda, French chalk, Fuller's earth. Their practical use.

2. Supplies of potassium permanganate, boric acid, boric wool and lint, carbolic acid, formaline, and a very small quantity of corrosive sublimate. The preparation of instructions for their use in emergency.

Useful as such a course may be made, it certainly has its limitations from the point of view of training in science. The course does not lend itself to the building up of a consistently logical body of doctrine. It is an intelligent treatment of a group of associated facts rather than the teaching of science.

Now consider the much more difficult subject of foods and food-substances. We will select the most difficult of all, the group commonly called " proteins ". It may be assumed that the pupil has already done a course of elementary inorganic chemistry, and has already done something to the easier parts of the study of food substances, say carbohydrates, fats and oils, milk, and flour. It is not assumed that she has done any appreciable amount of organic chemistry.

The Study of Proteins *

1. Examine a fresh egg.—An egg is really an undeveloped chick. Since the chick is developed from the egg, the egg must contain within itself all the building material necessary for the making of the chick, together with such a supply of nutriment as the latter requires until it is ready to be hatched. Weight of egg about 50 gm. (2 oz.): shell = 12 per cent; white = 58 per cent; yolk = 30 per cent.

2. Composition of *shell*? The *white* is a solution of protein shut up within a multitude of cells. " Beating up " the white of egg ruptures the cell-walls; the protein thus escapes, and the digestibility of the egg-white is increased. This protein is called egg-albumin. The *yolk* is the storehouse of nutriment for the young chick: contains a large proportion of fat—palmitin, stearin, and olein—present in the form of emulsion, and therefore easily digested. How could the presence of fat be proved? Colour of shell makes no difference to the composition of the egg. When kept, eggs become lighter; why? Cause of disagreeable smell in bad eggs. How to tell a fresh egg. Relative digestibility of raw eggs, lightly boiled eggs, and hard boiled eggs. Nutritive value of eggs. Custard powders.

* The old distinction between " proteid " and " protein " no longer obtains, and the latter term is in general use.

3. Examine egg-albumin (egg-white). Reaction with litmus? Solubility?

4. The action of heat upon egg-albumin. (Heat in test-tube in beaker of water.) Becomes cloudy at 58° C.; coagulates at 60°. Is coagulated albumin soluble? Heat more albumin in crucible to higher temperature; odour? Cf. with the heating of *gluten*. Put a little egg-albumin aside for a few days; putrefaction: nature of gas given off.

5. Dry some egg-albumin over a water-bath, mix it with soda-lime, and heat strongly in a test-tube. Ammonia now easily detected. Hence the albumin is a *compound of nitrogen*. The *casein* of milk-curd, the *gluten* of flour, the *albumin* of the egg, are all nitrogen compounds and belong to the class of food-stuffs known as *proteins*.

6. Examine some raw lean beef or mutton. Note bundles of fibres. How are the fibres held together?

7. Dry some lean meat in an air-oven (temperature 100°–105°). Percentage of contained water. Reduce the dried product by further heating to a white ash: percentage of mineral matter in lean meat. Composition of lean meat: 50 to 75 per cent of water, about 20 per cent of protein, with fat and mineral matter. The chief protein present is *myosin*. Composition of fish much the same: but some fish are very free from fat, while others are remarkable for the amount of oil they contain.

8. Effect of boiling on meat. Place in cold water, heat gradually, and note temperatures of changes. Water becomes cloudy at 58°; why? At about 71°, a scum forms; cause? Let the water simmer for half an hour, and record all changes; take out the meat and examine. Now plunge a piece of raw meat into *boiling* water. Contrast with previous experiment. Take out as before and examine. Cause of the formation of the " crust ". Its use. How are the contained juices prevented from escaping? Cf. the boiling of fish. Any objection to putting fish into boiling water? Roasting; broiling; frying: compare and contrast these methods with boiling. Cf. methods of cooking different joints. Stewing. Steaming. Reasons for cooking meat.

9. Beef-juices; beef-tea; bovril. Meat-extractives generally. Liebig's extract almost devoid of protein; mainly an exciter of gastric secretion; not a food, and even a doubtful stimulant.

10. Peas, beans, and lentils, all rich in nitrogen. Why, then, described as the " poor man's beef "? The contained protein is *legumin*. Legumin unites with lime salts, forming an insoluble compound. Why, then, is it difficult to cook peas and beans in hard water? Use of soda in the cooking. Nutritive value and digestibility of peas, beans, and lentils.

This is all very useful knowledge, the treatment is logical,

the experiments are mostly simple, and the facts stated without resort to experiment are, in the circumstances, permissible. But is such teaching *science* teaching? It is characterized by a repetition of very elementary experiments of much the same order of difficulty. No matter how excellent the actual teaching may be, it cannot be said that the work done is very exacting, or that the reasoning is very rigorous, or that there is a very serious training in systematized procedure. In short, it can hardly be regarded as work worthy of intelligent Sixth Form girls. The fact that the girls have no knowledge of organic chemistry makes it impossible to treat the subject as it ought to be treated from the point of view of *science*.

It is probably best to include all this kind of work under the head of *housecraft*. The principles of physics and chemistry are best taught independently, mainly before housecraft as a separate subject is taken up. Then the housecraft may be placed on a fairly rational, if not on a strictly scientific, basis. Reasons for processes will be discovered and understood, and homecraft may then become something more than a traditional routine, followed because mother followed it and she because *her* mother followed it, and so on. The subject as taught will consist largely of applications of principles of physics and chemistry already known, and in this way the earlier course in science, being used to throw light on new knowledge, will be greatly increased in value. But it is wiser not to talk about domestic *science*. It is preferable for the science mistress and the housecraft mistress each to stick to her own last. The two will collaborate closely, and although one will be teaching science and the other a craft, each will make constant use of the work of the other.

CHAPTER XXIX

Meteorology and Weather Forecasting

The Newer Aspects of the Subject

Since the beginning of the present century, our knowledge of the atmosphere has increased enormously, knowledge which has revolutionized our ideas of meteorology. Instead of ranking as a body of rather crude empiricism and doubtful conjecture, as it did thirty years ago, meteorology is now fairly definitely established on a scientific basis. The forecaster's work has become comparatively easy and certain.

If the subject is taught at all—and about this there is great difference of opinion—the following points seem to demand preliminary exposition and explanation:

Structure of the Atmosphere.—From the point of view of temperature, there are two shells or regions: a lower shell or region in which there is a fairly rapid " lapse " of temperature upwards, and an upper shell or region in which the lapse rate is approximately zero. An ascent shows that the transition from the region of falling temperature to the region where there is virtually no change with further height, is generally abrupt. The level at which this change takes place varies from 5 to 8 miles up.

But the upper region is not a region of uniform temperature. In the lower region, the isothermal surfaces are parallel to the surface of the earth. In the upper region, the isothermal surfaces are not even approximately horizontal; they are practically vertical.

The upper shell, in which there is no material change of temperature with height, is called the *stratosphere.* The lower shell, in which, as we have long known, the temperature lapses with the height, is called the *troposphere.*

We may look upon the *stratosphere* as the normal part of the whole atmosphere, the part unmodified by earth-surface conditions. It may be visualized as vertical columns or sheets,

each of practically uniform temperature: the isothermal surfaces are vertical. The *troposphere* consists of those lower parts of the atmosphere which, with the aid of water-vapour, have been modified by convection. It may be visualized as approximately horizontal layers, each of practically uniform temperature: the isothermal surfaces are horizontal.

The troposphere is not of uniform thickness; it is about twice the thickness at the equator as it is at the poles. Its upper boundary is called the *tropopause* and marks the limit of the operation of convection. If there was no convection the atmosphere would be all stratosphere.

Evidently the tropopause is not horizontal, though the stratosphere rests on it like a layer of oil on a layer of water. The tropopause is not fixed but is constantly fluctuating.

There is an unexpected and noteworthy reversal that all students of meteorology must bear in mind.—In the troposphere, the temperature not only decreases with height, but, at corresponding heights, it also decreases as we pass from the equator to the poles. In the stratosphere, the temperature does not decrease with height, and vertically it remains practically unchanged, though, at corresponding heights, it *increases* as we pass from the equator to the poles. For instance, at the earth's surface, the mean annual temperature at the equator is 50° warmer than at the poles; but at 12 miles above the surface, that is, in the stratosphere, the temperature difference at the equator and poles happens to be the same as before (50°), but in this case it is the polar region which is the warmer—a truly amazing reversal!

The tropopause may be visualized as a permanently separating surface between the stratosphere above with its vertical isothermal surfaces, and the troposphere below with its horizontal isothermal surfaces; now rising a little, locally, now falling a little, locally, depending on the convectional activity of the troposphere.

Source of Energy.—For the meteorologist, water in the form of vapour is the most important constituent of the

atmosphere. It provides not only the material for clouds, rain, snow, and hail, but also the means of supplying the energy which makes these things possible. Important meteorological functions hitherto attributed to warm air are now known to belong to the vapour which the warm air carries.

We may look upon the troposphere as originating in the persistent digging away of the underside of the stratosphere by convection of one sort or another which itself originates in the warmth and moisture developed at the earth's surface or in the loss of heat in the absence of the sun. Convection is largely dependent on water vapour.

The troposphere may be looked upon as the flywheel of a gigantic heat-engine—an engine for converting solar energy into the energy of the winds. It is in a state of perpetual motion, which we call the circulation of the atmosphere—the dynamical effect of heat received from the sun by radiation, communicated chiefly at the ground-level, and afterwards radiated into space.

It is known that the diminution of the intensity of solar radiation with the increasing obliquity of the sun's rays is due to absorption by the atmosphere, principally by the contained water vapour. If there was no water in the atmosphere, the intensity of solar radiation would reach and remain at a maximum throughout the period of sunlight, changing instantaneously to zero with the disappearance of the sun at sunset.

The main problem is: how does the atmospheric engine work?

MOVEMENTS OF THE AIR.—The decrease in temperature of the troposphere as we ascend varies from place to place and from time to time, but the average decrease is practically the same in all parts of the world. If we ignore the complicated conditions near the ground, the " lapse-rate " is the same for all parts of the world, from the equator to the poles; it increases regularly as we ascend. Whether air will rise or fall as the result of differences of temperature depends not only on an initial difference of temperature but also on the lapse-rate in the surrounding atmosphere. After rising a little way, a mass

of air may have no buoyancy left. But the question of ascending and descending air is complicated by the condensation of the water-vapour carried with it, and we can best take this into account by considerations of entropy.

Sir Napier Shaw has prepared diagrams showing the entropy throughout the normal atmosphere. These show surfaces of constant entropy that are nearly horizontal, lying almost like a series of stratified rocks.

On all movements of air in which heat is neither added nor extracted—for instance, by condensation or radiation—it must travel *along an isentropic* * *surface.* These isentropic surfaces act like physical restraints to the air, tending to prevent its moving in any but an almost horizontal direction. This thermal stratification rules out *ascending and descending currents* as a direct consequence of the normal temperature distribution of the atmosphere. That ascending currents do occur is, of course, true; we infer them, for instance, from the large amount of precipitation we measure. But in the stratified atmosphere these ascending currents are possible *only* if the air taking part in them receives sufficient heat on its ascent to raise its entropy at least to that of the surrounding atmosphere at each level. Heat is supplied by condensation of water-vapour, but *normally* air does not hold sufficient water-vapour to supply the requisite heat, and so cannot pierce the normal stratification.

The *descent* of air is a different matter, but air cannot descend through the stratification without the necessary heat being extracted. On the other hand, we know that air does descend, for an amount of air equivalent to that which goes up in ascending currents must come down somewhere. The solution of the problem seems to be that, practically, air never descends through its environment, but comes down *by the gradual subsidence of a whole column.* This is generally brought about by the air at the bottom of the column spreading under the surrounding air.

Thus it is essential for pupils to bear in mind that, nor-

* The now recognized form of *iso-entropic.*

mally, air moves along an isentropic surface, and that ascending and descending currents are the exception.

THE NEW AND THE OLD IDEAS.—Formerly, all atmospheric motion was referred to the ascent of warm air through cold air, and the descent of cold air through warm air. There was a permanent circulation from the equator to the poles in the upper atmosphere, with a return flow in the surface or middle layers.

The old idea was right to this extent—that the potential energy inherent in masses of air at different temperatures must be the origin of the kinetic energy of the winds. The main question is, how does the change from potential to kinetic energy take place?

Margules's work has led to an entirely new idea as to the method in which solar energy is converted into the kinetic energy of atmospheric motion. Instead of warm air rising vertically like the warm gases in a chimney, drawing air in at the bottom and delivering it at the top, two bodies of air, one warm and the other cold, are brought *side by side*; the cold mass slowly subsides, and pushes its way as a wedge of cold air under the warm air which is partly raised and partly drawn in above to replace the cold subsiding air. In the process the centre of gravity of the whole moving mass is gradually lowered, so providing the energy of the motion which we recognize as winds.

The essential difference between the new and the old ideas is that the two masses of air, in which the difference of temperature is the cause of the motion, *do not mix*. We start with two bodies of air side by side, with *a surface of sharp discontinuity between them*. In each body there is a different stratification of isentropic surfaces. In the warm body, the corresponding isentropic layers are all lower than in the cold body of air. There is a gradual adjustment to corresponding isentropic surfaces, but, in the process, the surface of discontinuity is a sliding surface, and no air crosses it.

SURFACES OF DISCONTINUITY.—The surfaces at which relatively cold and warm masses of air meet and slide over each

other can easily be recognized on meteorological charts and by observations in the upper atmosphere. On a stationary earth, a surface of discontinuity would rapidly disappear, or appear as a horizontal surface with all the cold air underneath and all the warm air above. Actually, we find inclined surfaces of discontinuity persisting for days together, and others which are apparently permanent. This arises from the effect of the rotation of the earth. Mathematical investigation shows that, on a rotating earth, the tendency of cold air to pass under warm air may be completely counterbalanced by forces due to the earth's rotation.

Bjerknes considers that there are three great permanent surfaces of discontinuity of this kind in the atmosphere: (1) that between the troposphere and stratosphere; (2) that between the trade-winds and the anti-trade winds above them; (3) that forming the " polar front ".

CYCLONES.—The old hypothesis that a cyclonic depression is a kind of chimney drawing air in below and giving it out at the top can no longer be held. A cyclone was sometimes described as a cylindrical vortex, with its axis nearly vertical, rolling along at a rate conjecturally dependent partly on the tilt, and with an axial uprush of air to fill up a central depression; this depression was nevertheless maintained and might be intensified by the whirl, the energy being derived from the condensation of vapour. If this were the true mechanism of a cyclone, we should expect to find a considerable amount of symmetry round the axis. The air would move in a continuous stream circulating round the centre but always approaching it; in other words, the stream-lines would be continuous spirals. There would also be little difference of temperature in the different parts of the cyclone, for the same air current would pass successively through all parts.

In reality the conditions are entirely different. When stream lines are drawn by the aid of the wind arrows on synoptic charts, it is impossible to connect them so that they circulate all round the depression. On the contrary, they are discon-

tinuous, the stream lines in certain parts meeting the stream lines in other parts almost at right angles. There are also large discontinuities of temperature, each set of stream lines having its own temperature. Further, it is found that the areas of rainfall are not confined to the central regions, but are broad bands radiating from the centre like spokes in a wheel, showing that the ascending air is not taking place mainly in the central region. Whatever cyclones may be, they are certainly not homogeneous rotating systems.

Bjerknes has given us much new knowledge of cyclones. We have to recognize that a cyclonic depression is the meeting-place of polar and equatorial air. Each body of air is *stable to vertical currents within itself*, but, where the two masses meet, readjustment is necessary; the surfaces of discontinuity tend to set themselves at the angle necessary for stability under the existing conditions of velocity and temperature. This involves the bodily raising of the warm air over the cold air, and a general sinking and spreading out of the cold air. The energy for the process is derived from the conversion of potential energy into kinetic energy as the centre of gravity of the air as a whole is slowly lowered during the readjustment of the air masses. The energy derived from the condensation of water-vapour is a very insignificant part of the energy developed in a cyclonic depression. But we still have much to learn about cyclones, and no hypothesis yet put forward to account for all the facts seems to have found general acceptance.

Were there no water-vapour in the troposphere, the "digging out" from the stratosphere would be greatly reduced, and the stratosphere would be brought down much nearer the surface and would be interfered with only by such convection as belongs to dry air. In fact, if there was no water vapour, the working of the atmospheric engine would be much simplified, because the atmosphere would then be transparent both for the solar radiation by which heat is gained and for the terrestrial radiation by which heat is lost. The last word has not been said by a very long way, either about the atmospheric engine as a whole or about that particular part of it we call cyclones.

The Teaching of the Subject

Meteorology is seldom taught except under the more general heading " climatology " taken as a branch of geography and not as a branch of science. It does not therefore receive great attention, just about enough to enable pupils to answer examination questions on cyclones, monsoons, and the like. But the older books are full of hypotheses now discarded, and the " facts " taught sometimes convey notions which are demonstrably wrong.

Is it desirable to teach the subject at all?

The answer is in the affirmative, though it is undesirable to ask questions on it in examinations. A good deal of the subject remains at the conjectural stage, and even the now generally accepted hypotheses are difficult to explain lucidly, if only because some of the necessary facts are themselves rather obscure except to experts. Great caution must be exercised in handling the subject, even with a Sixth Form.

Some of the best teachers in the past have attempted to give a foundation to the subject by analysing the conditions in this way:

1. Consider all the irregularities of the earth's surface to be levelled down, and to be wholly land or wholly water (in order that all *local* atmospheric variations may be ignored), and consider the earth's axis to be perpendicular to the plane of the ecliptic. What would be the air circulation due to the spinning only? to the action of the sun only? to the two things combined?

2. The same, with the earth's axis inclined?

3. The same as 2, with the existing variation of water and land distribution, including the variation of height in the land forms?

The idea is, of course, to consider the forces at work, one at a time. From a teaching point of view this is excellent, but the phenomena are vastly more complex than is here assumed. Such an analysis is based on the assumption that the meteorological data we can gather at the earth's surface are all sufficient, but it is now a commonplace that the data necessary must be obtained at all levels of the atmosphere, and we must frame our hypotheses in accordance with such of

these data as are undisputed facts. Even if the only factors concerned were a spinning earth and a blazing sun, it would be rash indeed to argue *a priori* that *therefore* the facts must be so and so. This may be good philosophy but it is certainly bad science.

Forecasting

The kind of data accumulated every day by the meteorological office, the methods of obtaining it from permanent local stations and from ships at sea, and the construction and interpretation of weather charts, should be known by all senior pupils. The methods of exploring the upper atmosphere should also be known. But only a very general knowledge of the forecaster's art can be taught. To the expert the art has become simple enough, but to the layman it is difficult.

The old method of forecasting was mainly empirical, and based on the work of Abercrombie. Abercrombie had sketched the distribution of weather about centres of high and low pressures, and forecasting was based on the determination of the movement of these pressure distributions where they appeared on the weather chart, the assumption being made that as the pressure system passed over a place the normal sequence of weather would be experienced.

Now the forecaster knows more about the structure of a depression. The pressure distribution is, of course, still the main factor, but the forecaster searches his chart for *indications of the surfaces of discontinuity*, and examines the characteristics of the air masses to see whether they are of polar or equatorial origin. In this way he is able to determine the structure of the cyclone, and whether it is developing or dying. Having determined where the surfaces of discontinuity are situated, he is able to say where rain may be expected, and he knows what weather changes will accompany the passage of each surface of discontinuity as it moves over the surface of the land. He is aided in this by observations taken in the upper atmosphere by means of pilot balloons and airplanes fitted out with meteorological instruments.

Concluding Remarks

It would be difficult to criticize a teacher who decided that meteorology was an entirely unsuitable subject of science for inclusion in a school course, especially if he argued that no experimental work is possible, and that lessons must be based on data accumulated by other people; that, in short, the teaching must be wholly deductive and didactic, and therefore be of less value than the teaching of most other branches of science. On the other hand, he might decide that an elementary knowledge of meteorology is now expected of all intelligent people, and that therefore a certain amount of time devoted to it would be usefully spent, even though the teaching would not be true science teaching. He might go further than this and urge that there are many other subjects which we cannot learn at first-hand, and that it is therefore useful for boys to learn how to use admittedly true facts obtained second-hand, and to examine hypotheses which have been framed in explanation of particular groupings of such facts.

Geography teachers will probably be wise to follow Mr. Lempfert's order of treatment of the subject. The earlier chapters in his *Meteorology* deal with " weather maps ", pressure, winds, temperature, clouds, and relation of winds to pressure distribution, chapters which show how available meteorological records are made and what deductions may safely be drawn from them. As the book develops, it becomes less elementary, and only a teacher well versed in physical science is likely to cope with it properly.

Teachers desiring to take up this difficult subject seriously must consult Sir Napier Shaw's *Forecasting Weather*, *Manual of Meteorology* (2 vols.), and *The Air and its Ways*, books too difficult for school use, but necessary for teachers of meteorology to read. An excellent introduction to them is Geddes's *Meteorology*. A good recent German standard work is *Wetter und Wettervorhersage* (*Synoptische Meteorologie*) by Dr. Albert Defant. Anything written by Dr. G. C. Simpson, the present Director of the Meteorological Office, is always illuminating.

PART III

EXTENDED CONSIDERATIONS FOR SIXTH FORMS

A Sixth Form is a Form doing work beyond School Certificate stage, and such work ought to be something more than the continuance of the same type of work previously done. Sixth Form boys ought to begin to weave together the threads drawn from different subjects, and get some idea of science as a whole. They ought to know something of, e.g., the work on which so many of the world's great physicists have been concentrating for years—the constitution of the atom; and this, in its turn, means fairly advanced work in physics and astrophysics, and chemistry. They ought to have a good all-round knowledge of elementary biology. They ought also to know something about the foundations of science, and have some elementary notions of the philosophical implications. The work done should be work for the majority, those who complete their education at school. Those who pass on to the university will naturally have greater opportunities, for seeing things in a proper perspective, than can be given at school.

One or two of the newer universities are still preparing students for the so-called " Intermediate " examinations, apparently failing to recognize that work of this grade has now become the staple diet of the First Year of the Sixth Form, as indeed it already has been for many years past both in our own Public Schools and in schools on the Continent. The

complaint is made by representatives of those universities that such work cannot be digested by boys of 17! Still, Sixth Form teachers of science should remember that if they entrench themselves behind such a syllabus as the Intermediate examination syllabus, they do run the risk of being charged with incompetence. If Sixth Form work is of a mere memory-clogging character, the exacting intellectual discipline which is the first essential during these two years will take a second place, and the university critic will then not be slow to seize his opportunity.

CHAPTER XXX

Sixth Form Work and its Critics

Sixth Form work of the present day tends to follow the broad lines of the Board of Education " Advanced Courses ", and in science this means that from two-thirds to three-quarters of the school time is devoted to science subjects and (generally) mathematics. The usual plan is for two science subjects to be included, and commonly these are either chemistry and physics or chemistry and biology. The remaining time is given up to English and other non-science subjects.

One critic of this work utters his complaint in this way: " Those pupils who show any aptitude for science are mostly led, for the last two years at school, to tread the path of specialization on their journey to the universities. They arrive at the universities embryo chemists, physicists, or botanists where they are hatched out as full-fledged specialists destined to act as guides to others along the same narrow paths, or to apply their specialized knowledge to industry. The revolt against the old-fashioned classical education was successful because the teaching of the classics had become so specialized that the main object of the study was obscured. It encouraged the worst forms of pedantry. There is abundant evidence that the teaching of science is suffering from the same disease. The spirit of science, the systematic observation of facts, the conception of hypotheses, to be discarded if they cannot be verified over a complete range of observations, or enunciated as universal if they stand such test, the constant challenge to established precedents or authority, is apt to be obscured by a mass of technical trivialities which passes for scholarship."

Another writer says: "Many university teachers are seriously disturbed by the obvious growth of specialization in the schools, and especially by the results of such teaching on the mental outlook and capacity of university entrants. It is not true to say that education is general to the age of 16, and that specialization only appears after that age. Specialization has a sinister tendency to creep downwards."

These criticisms are not just, though there is some small measure of truth in the first. The country considered as a whole, education up to the School Certificate stage is most certainly general and not specialist. There is this difference between secondary education of the present day and that at the public schools thirty or forty years ago: then, the work was nearly always specialist, sometimes even in the Preparatory schools, and classics was almost always the subject in which specialization took place; but at the present time education is quite general up to the Fifth Form (School Certificate stage), though *in some measure* it is specialist in the Sixth. This Sixth Form specialization is kept within bounds; the basis of the work done is very much broader than the subsequent university work. It is rightly argued that the Sixth Form boy ought to have to wrestle with serious intellectual difficulties, whatever branches of knowledge be chosen for the purpose, and not to devote his time to the same grade of work that characterized his pre-sixteen education. Specialization in the correct sense of the term does not usually now begin until the boy reaches the university. There is another important point: schools have to provide courses of instruction for the majority, not for the minority that proceed to the university, and specialization for that majority is wholly unnecessary.

It is, however, quite true that boys working for university scholarships in science have to face the drudgery of reading up masses of indigestible stuff for the purpose of answering questions on obscure points of detail: that is the fault of the university authorities, not of science teachers at the schools. And some of the questions asked in Higher Certificate papers

are unsuitable; they presuppose a knowledge of the technical minutiæ of, say, organic chemistry, or of mathematical physics; and the time devoted to the teaching of this sort of thing is certainly wasted. But here, again, it is not the fault of the science teachers but the fault of examiners who do not understand their job.

A leading science master wrote to *Nature* (24th March, 1928), saying that he had looked through a few chemistry papers set recently at one group of Cambridge colleges and had found questions on (1) the alloys of mercury and potassium; (2) ionic transport numbers; (3) the manufacture of lithopone; (4) the synthesis of dimethylacetic acid.—Comment on this calls for strong language. If such questions are set, how can science teachers be expected to adopt rational teaching methods?

Another critic has said: " The years 16 to 18 should be a breathing-space between the School Certificate examination and the commencement of university studies; they should provide a period of wide reading rather than intensive study of a restricted syllabus, a period for ' browsing ', for the enjoyment of poetry and art, for leisurely thinking."—Does that critic seriously urge that the years 16 to 18 should be devoted to lotus-eating? Would he argue that it is unnecessary for boys at that critical age to wrestle with serious intellectual problems, for instance, to read science in such a way as to be compelled to get to grips with the relation between cause and effect? that, instead, they should devote their time to making a superficial acquaintance with natural phenomena—catching butterflies and blowing soap-bubbles—and writing odes to the Queen of Mars? No. Sixth Form boys must be taught to *work*.

There is, however, one very important feature of Sixth Form science that calls for really serious criticism, and that is that the prescribed course of work is not liberal enough. At the very least, a general course of biology should be included in the course, be the more substantive subjects what they may. This does not mean that any part of the course should be allowed to become intellectually less exacting. The necessary time for the new subject may be found by cutting out of the

chemistry, physics, and mathematics courses all unnecessary "frills"—technicalities which are of no importance to anybody save the specialist.

Any Sixth Form course must be so designed as to demand close attention and close application. The training in method must become more and more severe; the scrutiny of facts and of hypotheses must become more and more critical. Reasoning will sometimes have to be carried far ahead of basic principles, but it must always be traceable back to them. There must be no weak links in chains of reasoning.

Another essential feature of Sixth Form work is that pupils should be fully conscious that a lesson is sometimes gathering into its ambit knowledge previously obtained from several subjects. The reasoning employed will thus depend on a clear grasp of the relations of many facts obtained from different sources on different occasions, facts which hitherto have seemed to have no obvious relations at all. If any of this old work has been imperfectly done, revision is essential, or the new work will be valueless.—We outline subject-matter for a short series of lessons on two new subjects: (1) the structure of the atom, (2) relativity. Each subject will call for, by way of an introduction, a good deal of revision of old work, and this necessary old work we summarize.

CHAPTER XXXI

The Structure of the Atom

The first five sections of this chapter contain brief outlines of a necessary revision course: it is assumed that the pupils have already taken courses in physics, including mechanics and elementary spectroscopy, and have some knowledge of radioactivity and astronomy. Some of this work will probably have been done in the first year of the Sixth Form course. The sequence of topics adopted is found to work well in practice.

Astronomical Considerations

Angular momentum $= mr^2\omega$; acceleration towards centre $= \omega^2 r$; centripetal force $= mv^2/r$.

Since $r^3 \propto t^2$ (Kepler's third law), it follows that rv^2 is constant for all orbits round a single attracting centre.

The orbit of a projectile is curved; it is a parabola (really an elongated ellipse). The original impulse given to the moon is enough to keep it falling back to earth.

For centripetal force necessary to curve the path into a circle, $mv^2/r = mg$ (weight), or $v = \sqrt{gR} = \sqrt{\dfrac{32 \times 4000}{3 \times 1760}}$ $= 5$ (miles a second).

Shell fired at 5 miles a second (300 miles a minute) (if beyond obstruction of earth's atmosphere) would become a moon with a period of 2 hours. If velocity less than this, it would hit the earth sooner or later. If $300\sqrt{2}$ or more miles a minute it would go off to infinity.

Body falling from infinite distance: under inverse square law, v (on reaching earth) $= \sqrt{2gR}$. This same velocity would enable the body to get away to infinity; it is equal to $\sqrt{2}$ times the speed necessary for rotation.

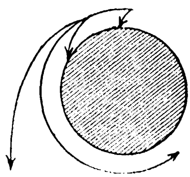


Fig. 2

Kinetic energy $\propto v^2$, and is written $\frac{1}{2}mv^2$. Hence, energy acquired by a body falling from infinity $= mgR$. This energy which a body must possess to enable it to revolve round the earth $= \frac{1}{2}mgR =$ the energy that would be acquired by a free fall through a height equal to half the radius of the earth, whereas the energy from infinity, or ESCAPE ENERGY, $=$ the free fall under uniform gravity through a height equal to the whole radius.

The moon as an example. Here, distance is 60 times earth's radius. Hence speed of moon in its orbit is $5/\sqrt{60}$ miles a second; speed of escape is $5\sqrt{2}/\sqrt{60}$ miles per second. Thus, if the moon could be given an extra push, to make it travel about half as fast again, it would bid the earth a final good-bye.

ENERGY needed for escape is just double the energy required for circular revolution. Thus if the revolution energy of any planet were doubled, it would escape control and fly away.

(All this is of great importance in the consideration of electronic orbits.)

The Periodic Law

Mendelieff's and Newlands's work: if the elements be arranged in a table in ascending order of atomic weights, the elements with similar physical and chemical properties appear at recurring intervals. The nuclear theory of the atom gave a new insight into the origin of these properties.

The properties are of two independent classes: (1) those (ordinary physical and chemical properties) depending on the constitution of the cluster of revolving electrons; (2) those depending on the actual internal structure of the nucleus (radioactive properties).

That the two sets of properties are independent is shown by the existence of substances indistinguishable from one another by any ordinary physical and chemical tests, but whose atomic weights differ and whose radioactive properties differ. These *isotopes* occupy the " same position " in the Periodic Table. In 1913 Soddy suggested that atoms might differ in weight but in no other particular; this was verified by Thomson and Aston.

Radioactivity

Kinds of Radiation.—How demonstrated:

α-rays: how identified as He atoms; $+^{ly}$ charged particles
β-rays: considered as cathode rays consisting of electrons.
γ-rays: X-rays of very short wave-length.

Nuclear Nature of the Atom.—The massive nucleus of an atom consists of two distinct parts: (1) an inert mass of *inactive* protons and electrons; (2) a number of *charged* protons. The latter hold an equal number of electrons together, into a sort of solar system.

Atomic weight = total number of protons.

Atomic number = number of active protons (usually about half the total).

Electrons and protons are − and + units of electricity. Relative weights, 1 : 1830. All protons assumed to be alike; so all electrons.

Evidence, direct and inferential.—*Rutherford's* method of bombarding N atoms (each containing 14 protons); 2 protons flung out violently as atoms of H; the other 12 hung together in groups of 4, as atoms of He. But we may not *infer* that N consists of 3 He and 2 H atoms, though the N nucleus must contain H in *some* way.

Are all elements built up of H atoms?

Atomic weight of He = 4. If H = 1, we should feel pretty sure that He is built up of 4 atoms of H. But H = 1·0077.

Hypothesis.—Every electric charge has a certain mass associated with it, and the inertia of matter is due to a magnetic field of moving electric charges. But if + and − charges are packed very closely together, *the combined inertias are less than the sum of the separate inertias*, because of the tendency to neutralization. Some of the *mass* will have disappeared. Thus if the He nucleus consists of 4 atoms of H, they must be packed tightly together, with a resulting diminished mass from 1·0077 × 4 to 1 × 4. H in combination is 1; free, 1·0077. Thus He and all other atoms may be composed of H, but of tightly packed H.

Wilson's experiments and photographs.—Inferences therefrom.

Collect the results of the experimental work of Rutherford, Thomson, Wilson, and others and show how converging lines of evidence all point to the main hypothesis: *every atom has a central solid compact nucleus, positively charged, round which negative electrons revolve, according to the inverse square law.* Thus the atom seems to be a miniature astronomical system. If this be so, the problem is, **does this system obey the ordinary laws of dynamics?**

How *e* (the fundamental electrical unit) and *m* (mass of electron) are determined. By experiment we know m/e, v, nev, and n. These data are enough to determine and to verify e and m.

Ætherial Radiation and Wave Measurement

The history of spectroscopy. Different kinds of spectra: the ever-increasing complexity in number of lines. Detection of order and law amongst the lines: a definite *series* belongs to each element. The H series the simplest. Characteristics of the series. Repetition of similar series in the infra-red and ultra-violet. How these series differ and how they are alike.

What the lines represent: waves of definite length and frequency.

How wave-lengths are measured. Wave-length compared with dimensions of diffracting aperture. Diffraction grating more effective than diffraction slit ($\lambda = d \sin\theta$). But the dimensions of even the best grating are too coarse for the measurement of X-rays. Laue's discovery of the use to which space-structure of crystals may be put; the X-ray spectrometer. Photograms and their interpretation.

How all ætherial waves are *alike*: same velocity, all subject to same laws of refraction, reflection, polarization, interference.

How all the waves *differ*: only in frequency and length.

For all waves, $v = n\lambda$; v and λ can be measured; hence n is known. Wave-length expressed in *Ångström units* (A.U.) $= 10^{-8}$ cm. $= 1/10\mu\mu$. Spectral lines represented by wave-*numbers*, obtained by dividing 10^8 by wave-lengths.*

Radiation at its source—due to changes in velocity of electrons.

Present knowledge of electromagnetic radiation extends over a range of 70 octaves (wave-lengths, ·001 A.U. to 10,000 km.). The B.B.C. uses 2 octaves. Visible spectrum extends over 1 octave (3900 to 7600 A.U.).

The Hydrogen Spectrum

The best known lines in the H spectrum are the three discovered by Fraunhofer as black lines in the solar spectrum;

* See pp. 293–4.

the one in the red he labelled C; the one in the greenish blue, F; the one in the indigo, G. We now call then B, C, and D respectively, and we know a fourth well-known line E, as well as a number of fainter lines crowded together and finally coming to a limit in the form of a " fade-away ", and termed Z. Then we think of the series as B, C, D, E, . . . , Z. The series itself is called the " L " series. It is the one series in the visible spectrum. There is a similar series (K) in the ultra-violet, and still others (M, N, O) in the infra-red. In each series the same letters (B, C, D, E, . . . , Z) are used to distinguish the spectral lines, though not all the lines appear in the various infra-red series.—Make blackboard sketches to show the relations of all these lines. See figs. 3 and 4.

The Balmer Formula

This subject is best introduced by giving the boys a "series" of numbers from which they have to discover the general term. They will have had some experience of this in algebraic series. For instance, the general term of the series $1, \frac{1}{4}, \frac{1}{9}, \frac{1}{16}, \ldots$ is $\frac{1}{n^2}$. Such a series may be masked; e.g. 3600, 900, 400, 225, 144. Obviously the general term is $\frac{1}{n^2} \times 3600$, and the 3600 may conveniently be called a constant.

Hagenbach measured the wave-lengths of the 5 principal H lines in the visible spectrum. The results were:

6563·04
4861·49
4340·66
4101·90
3970·25

But he could not find the general term, or, indeed, any relation amongst the numbers. He handed over the problem to Balmer, an assistant master in a Basel secondary school. After many trials, Balmer found the constant, viz. 3645·6, since called the

" Balmer constant " and written " B ". Here is the solution he gave to Hagenbach.

$$
\begin{array}{lllll}
6563{\cdot}04 = \mathrm{B} \times 1{\cdot}8 & = \mathrm{B} \times \frac{9}{5} & = \mathrm{B} \times \frac{9}{5} & = \mathrm{B}\left(\dfrac{3^2}{3^2 - 2^2}\right) \\
4861{\cdot}49 = \mathrm{B} \times 1{\cdot}\dot{3} & = \mathrm{B} \times \frac{4}{3} & = \mathrm{B} \times \frac{16}{12} & = \mathrm{B}\left(\dfrac{4^2}{4^2 - 2^2}\right) \\
4340{\cdot}66 = \mathrm{B} \times 1{\cdot}190476 & = \mathrm{B} \times \frac{25}{21} & = \mathrm{B} \times \frac{25}{21} & = \mathrm{B}\left(\dfrac{5^2}{5^2 - 2^2}\right) \\
4101{\cdot}90 = \mathrm{B} \times 1{\cdot}125 & = \mathrm{B} \times \frac{9}{8} & = \mathrm{B} \times \frac{36}{32} & = \mathrm{B}\left(\dfrac{6^2}{6^2 - 2^2}\right) \\
3970{\cdot}25 = \mathrm{B} \times 1{\cdot}0\dot{8} & = \mathrm{B} \times \frac{49}{45} & = \mathrm{B} \times \frac{49}{45} & = \mathrm{B}\left(\dfrac{7^2}{7^2 - 2^2}\right)
\end{array}
$$

Thus the general term is $\mathrm{B}\left(\dfrac{n^2}{n^2 - 2^2}\right)$; that is, the wave-length, λ, is

$$\lambda = \mathrm{B}\left(\frac{n^2}{n^2 - 2^2}\right),$$

where n represents the natural numbers 3, 4, 5, 6, 7.

If *frequencies* (reciprocals of lengths, since $v = n\lambda$) had been given, a formula could have been found just as easily. The five numbers in the first column below represent the frequencies corresponding, respectively, to the five wave-lengths above. In this case the constant is 109678, now called the " Rydberg constant " and written R.

$$
\begin{array}{lllll}
15241 = \mathrm{R} \times {\cdot}13\dot{8} & = \mathrm{R} \times \frac{5}{36} & = \mathrm{R}\left(\frac{1}{4} - \frac{1}{9}\right) & = \mathrm{R}\left(\dfrac{1}{2^2} - \dfrac{1}{3^2}\right) \\
20575 = \mathrm{R} \times {\cdot}1875 & = \mathrm{R} \times \frac{3}{16} & = \mathrm{R}\left(\frac{1}{4} - \frac{1}{16}\right) & = \mathrm{R}\left(\dfrac{1}{2^2} - \dfrac{1}{4^2}\right) \\
23044 = \mathrm{R} \times {\cdot}21 & = \mathrm{R} \times \frac{21}{100} & = \mathrm{R}\left(\frac{1}{4} - \frac{1}{25}\right) & = \mathrm{R}\left(\dfrac{1}{2^2} - \dfrac{1}{5^2}\right) \\
24386 = \mathrm{R} \times {\cdot}\dot{2} & = \mathrm{R} \times \frac{2}{9} & = \mathrm{R}\left(\frac{1}{4} - \frac{1}{36}\right) & = \mathrm{R}\left(\dfrac{1}{2^2} - \dfrac{1}{6^2}\right) \\
25194 = \mathrm{R} \times {\cdot}2\dot{3} & = \mathrm{R} \times \frac{45}{196} & = \mathrm{R}\left(\frac{1}{4} - \frac{1}{49}\right) & = \mathrm{R}\left(\dfrac{1}{2^2} - \dfrac{1}{7^2}\right)
\end{array}
$$

$$\text{Thus } n \text{ (wave-frequency)} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right),$$

where n represents the natural numbers 3, 4, 5, 6, 7.

Note that the formula may be written $R\left(\frac{n^2 - 2^2}{4n^2}\right)$. Compare this with $B\left(\frac{n^2}{n^2 - 2^2}\right)$ above. Evidently $B = 4/R$.

The *constant* might have been written 4R instead of R, and would then have been the reciprocal of B. But R is now an important constant in other connexions. Slightly different values are given to it by different authorities.

(The *units* used do not affect the general result.)

The Grouping of the Different Hydrogen Series

Here is a diagrammatic view of the successive Hydrogen series in the spectrum. The L series is in the visible spectrum.

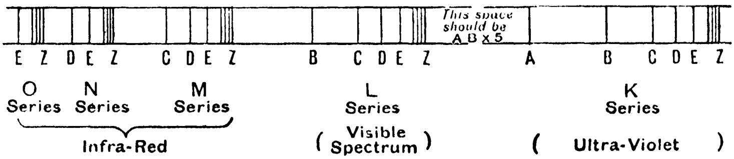


Fig. 3

The L series in the visible spectrum was the first discovered. When the other series were discovered, they all *seemed* similar to the L series. The wave-lengths were measured: did they square with the Balmer formula? These points should be noted:

1. The first (or K) series is far up in the ultra-violet.
2. The second or original Balmer (or L) series is in the visible spectrum.
3. The third, fourth, and fifth series (M, N, O) are in the infra-red.
4. The " head " of each series is a fade-away called Z.

5. The other end of each series is called the "fundamental". The fundamental of the K series is called A; of the L series, B; of the M series, C; and so on.

6. The first and second series are a long way apart, about 5 times the length of the distance AB.

7. The K series less the A line gives the L series; the L series less the B line gives the M series; and so on.

8. The spacing between the lines (between C and D, for instance) seems to be the same for all.

Ritz tried a modified formula $\frac{1}{m^2} - \frac{1}{n^2}$, giving different values of m to the successive series (values of n as before). Writing it in the form $B\left(\frac{1}{m^2} - \frac{1}{n^2}\right)$, he gave B the arbitrary value 900. This merely affects the scale, of course, and not the relative values.

Lines, and Values of n.	Series, and Values of m.					Interval Differences.
	K; 1	L; 2	M; 3.	N; 4.	O; 5.	
A; 2	108	0	—	—	—	
B; 3	128	20	0	—	—	20
C; 4	135	27	7	0	—	7
D; 5	138·24	30·24	10·24	3·24	0	3·24
E; 6	140	32	12	5	1·76	1·76
..	..	..	..	..	..	
..	..	..	..	..	..	
..	..	..	..	..	..	
Z; ∞	144	36	16	9	5·76	—

In the above table, let the pupils note carefully:

1. The relatively large values of the frequencies in the K and L series, and the consequently relatively long distance apart of these series in the spectrum.

2. The intervals between the corresponding lines, shown in last column, are actually the same in all the series, as appearances led to believe.

3. The intervals diminish as n increases.

4. The head (Z) of each series is the same distance from the corresponding lines.

5. The intervals in each series are identical except that: (1) they occur in different absolute positions; (2) an earlier series has one fundamental line on the left more than the next later series has. Thus only the K series has line A.

6. m fixes the number of the series; $n - m$ fixes the number of each line in the series.

It is now easy to see that if a spectrum is cut up, the series will fit exactly over each other thus:

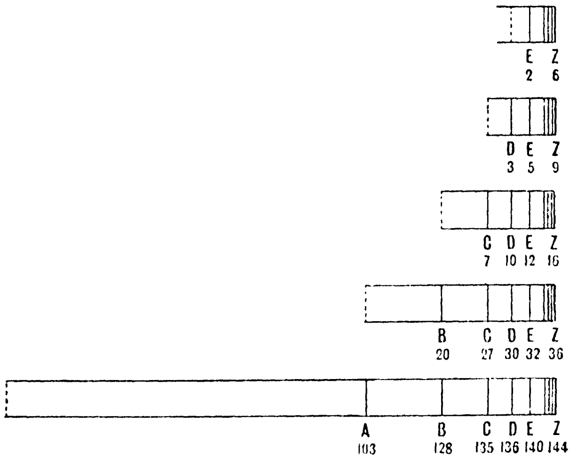


Fig. 4

The infra-red series beyond the O series are ignored. In practice even the O series is generally ignored.

Bohr's Interpretation

Bohr suspected that there was **some intimate relation between these series of spectrum lines and some sort of astronomical model,** and he asked himself how he could reconcile the two following apparently antagonistic facts:

1. *According to the Ritz law* (the generalized Balmer law) the frequencies of vibration of successive lines in the spectrum are represented by the difference of the reciprocals of the squares of the natural numbers.

2. *According to the law of gravitational orbits*, the energy of a planet is proportional to the reciprocal of the radius of its orbit.

Bohr applied the quantum theory to Rutherford's astronomical model of the H atom, and he postulated that, although *any* planetary orbit round the *sun* is conceivable (depending merely on the original impulse with which the planet was originally shot forth), *there could be only specific orbits for electrons, the radii of these proceeding as the squares of the natural numbers*. This granted, everything else followed.

When considered astronomically, the postulated succession of orbital radii as the squares of the natural numbers, requires that the rate of sweeping areas, or the moment of momentum, of an electron revolving inside the atom, is a quantity that proceeds by indivisible steps from one orbit to the next, and that energy is emitted only when an electron jumps from orbit to orbit. For if $r \propto n^2$, then $vr \propto n$ (Kepler's third law). This is expressible by saying that the moment of momentum is an integer multiple of some atomic unit.

Each orbit must have a characteristic rate of revolution, and, as in astronomy, an electron in a smaller and inner orbit must have a greater velocity than an electron in an outer.

The innermost orbit, called the K orbit, is a one-quantum orbit. The velocity in it is 1/140 the velocity of light, and the revolution number $= 6000 \times 10^{12}$ per second. In this orbit we have the highest frequency and shortest wave-length. It is the most stable orbit, and the H electron is normally in it.

The next orbit, the L orbit, is a two-quantum orbit. Then follow the M and N orbits, farther and farther from the nucleus; and still other orbits beyond, which may be ignored.

By sudden excitation from without (heat-motion, collision, electric-fields, cathode-rays, X-rays, &c.), an electron is apparently jerked out from an inner orbit into an outer orbit, but

it then has less stability. Left to itself, it jumps back sooner or later into some inner orbit. During this jump back, energy is liberated, and is emitted in the form of mono-chromatic radiation, i.e. radiation of one wave-length. Only during these transitions is the light-energy radiated. The energy emitted is the difference of the energy in the initial and final orbits. The frequency of the spectral lines produced by the transition is thus determined.

Thus every spectral line is produced by an electron jumping from one orbit to another. The particular rate of vibration depends both on the orbit jumped from and the orbit jumped into. A study of the spectra enables us to specify these two orbits.

An electron revolving steadily in an orbit does not disturb the æther. But a jumping electron gives a sort of kick to the æther and sets up a wave. The frequency of this wave depends on the violence of the kick, i.e. on the energy liberated.

To excite K radiation and to produce K lines, an electron must be jerked from the K orbit either into an outer orbit or away to " infinity " (a relatively great distance). The K " shell " of electrons (only 1 in H) tries to complete itself again, and the missing electron may be furnished from the L, or the M, or the N, or any other orbit. Whereas the process of excitation was accompanied by a gain of energy, the converse process takes place with loss of energy. According as the missing electron returns to the K orbit from the L, M, or N orbit, the energy set free will be different in amount. Hence there will be various possible K radiations, each of them represented by a definite wave-length, and all of them together giving the K series of lines. The K series occur high up in the violet.

To excite L radiation, an electron must be jerked out of the L orbit into an outer orbit. The L lines are the original Balmer series and occur in the visible spectrum. The characteristic red line (Fraunhofer C) is produced by a jump from the M orbit to the L orbit; the blue line, by a jump from N to L.

And so on.

The *series*, and the positions of *lines in series*, are thus determined:

1. The *series* is determined by the orbit *into* which electron jumps.
2. The *lines in a series* are determined by the orbit *from* which electron jumps.
3. The *fundamental* (lowest) line of a series represents a jump from the next orbit.
4. The *head* (highest) line of a series represent a jump from " infinity ". The results may be shown diagrammatically, thus:

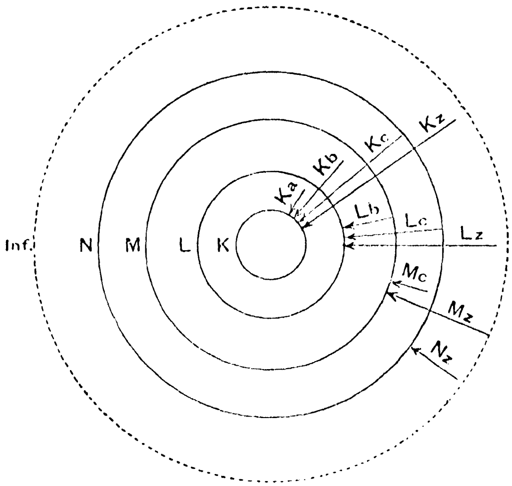


Fig. 5

Since each series is connected with one orbit, why is there a series of lines instead of only one line?—If electrons all jumped from the same outer orbit into (say) the L orbit, their radiation *would* consist of only one line. But if the H is strongly agitated, electrons will probably be jerked into many of the outer orbits; hence the jumps back represent different energies, different frequencies, and different lines. We are always dealing with *many* H atoms, not with only one.

Energy Considerations

The different orbits are characterized by different energies, which are inversely as the radii. Thus the frequencies of vibration characteristic of the different jumps are all different.

An electron falling inwards under electrical attraction loses potential energy and gains kinetic. The latter is twice that required for revolution in a circular orbit at the given position. Hence it gets rid of the other half by radiation. It is a remarkable thing that half the kinetic energy possessed at a certain stage suddenly goes away in radiation of a definite frequency, depending on where it has come from and where it has got to. This discontinuous behaviour has not been explained.

If nucleus is charged with $+E$, and an electron with $-e$, the force of attraction at any distance r is $Ee/2r$, and this constitutes the centripetal force mv^2/r, i.e. $\frac{1}{2}mv^2 = Ee/2r$. The additional energy to be given to the electron to enable it to escape is also $Ee/2r$. Hence energy of escape $= Ee/r$. It is the energy which it could have acquired by falling into its position from infinity.

If the additional energy given to a revolving electron is, (1) as much as it already possesses, it flies away to infinity; (2) less than this, but equal to a critical value, the electron changes its orbit; (3) less than the critical value, nothing happens.

Since the radii of the orbits are represented by square numbers, the total *energy* corresponding to each orbit (which we know to be inversely as the distance) will be represented by the *reciprocals* of the square numbers. Thus, if the total energy associated with the K orbit is 1, that in the L orbit is $\frac{1}{4}$. Hence the step or difference in the energy from K to L is $\frac{3}{4}$; from K to M, $\frac{8}{9}$; from L to M, $\frac{5}{36}$; and so on. The energy in orbit N is $\frac{1}{16}$; hence to make an electron jump from K to N, $\frac{15}{16}$ of its energy must be supplied to it. (A very little more would make it escape altogether.) And that is the amount of energy that will be emitted when the reverse step is taken.

If the orbits are represented by horizontal lines, the energy

differences between the levels are easily indicated. In the succession of energy steps, the difference in height between two steps shows the energy liberated when an electron jumps from a higher to a lower step.

For lines of a series to be emitted *at all*, there must be electrons in the jumping-off orbit. If very few of the atoms contain such electrons, the corresponding lines will be faint.

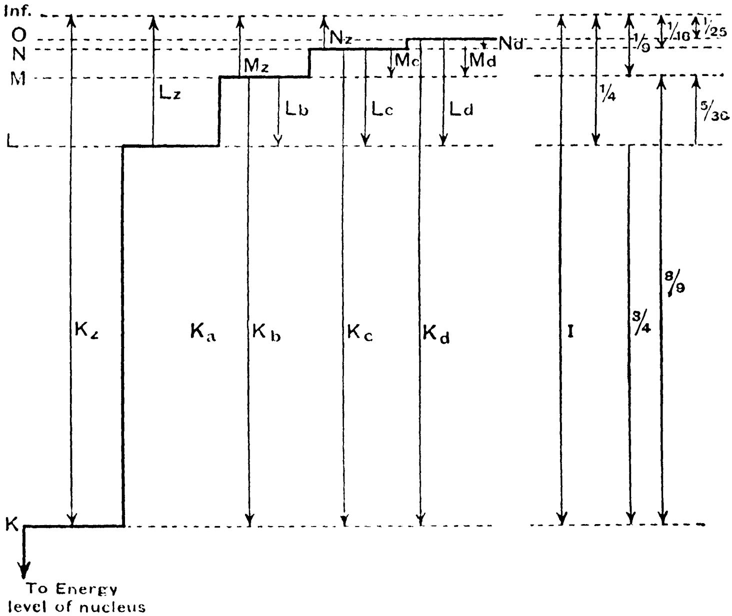


Fig. 6

It was Planck who saw that the connexion between the radiating atoms and the energy they emitted could not be accounted for by any theory of *continuous* emission. Either definite portions of energy are emitted or none at all. Regularity and law remain, but everything takes place in *steps*, in *gushes*. The steps are not equal. Planck's *quantum* is a natural constant, accurately measurable. It is associated with the angular momentum of the revolving electron.

For the interior of the atom, the older dynamics is still effective but requires supplementing, the phenomena being almost independent of such ordinary physical conditions of temperature and pressure.

Moseley's Discovery

Moseley photographed the X-ray spectra of different elements. To produce the spectra, the elements were successively fixed into the X-ray bulb as anti-cathodes, and thus the characteristic rays were excited directly by means of cathode rays. By varying the fixed position of the crystal, he contrived to establish the region of wave-lengths for the prominent K series. The measured wave-lengths of the K lines for seven elements are shown in the second column of the following table.

l = wave-length, n = frequency. Since frequencies are inversely as wave-lengths, $n = 1/l$. R = the Rydberg-Ritz constant (the universal wave-number).

Elements.	l (K Series).	$\frac{n}{R}$.	$\sqrt{\frac{n}{R}}$.	Differences of $\sqrt{\frac{n}{R}}$.
Na	11883·6	76·683	8·759	
				·853
Mg	9867·75	92·348	9·610	
				·856
Al	8319·40	109·535	10·466	
				·856
Si	7109·17	128·182	11·322	
				·859
P	6141·71	148·374	12·181	
				·857
S	5360·66	169·992	13·038	
				·859
Cl	4721·85	192·99	13·897	

Similar results are obtained with all the other series, and with all the other elements, within the limits of experimental error. (The ratio n/R is a convenient number independent of the units of measurement.)

Thus the amazing discovery was made that the 92 elements may be arranged in order in such a way that the square roots of the frequencies of the corresponding spectrum lines form an A.P. If we multiply $\sqrt{n}$ by such a constant as to bring the common difference to unity, we get the series of *atomic numbers* 1–92. Thus the different elements in the atomic series climb the ladder of frequency by regular and equal steps.

Other points demanding the pupils' careful attention:

1. The *atomic number* gives the total number of active protons in the nucleus, also the number of revolving electrons. The number is more immediately vital to chemistry and spectroscopy than is the atomic weight.
2. Reconsideration of the Periodic Law. The significance of the grouping of the 92 elements: the periodic numbers 2, 8, 8, 18, 18, 32, 6. " Shells " of electrons. Valency.
3. Stability of atomic systems.

(Further selected passages from Lodge's *Atoms and Rays* and from Sommerfeld's *Atomic Structure and Spectral Lines* might now be given to the more mathematically inclined boys of the Sixth Form.)

A Necessary Warning

The astronomical model of the atom has been presented to us with such extraordinary vividness, and it co-ordinates the facts of spectroscopy in such a remarkable way, that it is difficult to bring ourselves to believe either that the picture is conventional and purely hypothetical or that it is extremely unlikely to be in harmony with reality. The hypothesis has proved wonderfully fruitful, not because we have succeeded in identifying the particular capers cut by the electrons in the atomic gymnasia but because of the *numerical relations* it includes. Most of the actual evidence that gave rise to the hypothesis consisted of mere records of scale readings from instruments. That electrons actually exist and that their approxi-

mate dimensions are known, there is hardly any room left for doubt. That one element differs from another in the number of electrons within the respective atoms is also a matter of reasonable certainty. But the planetary picture? No. The picture is just a pretty analogy borrowed from astronomy, and pupils should be advised not to assume that it is really anything more.

CHAPTER XXXII

Relativity

Why Beginners find Relativity so Difficult

Inasmuch as relativity is transforming our fundamental notions of physics, and therefore of science generally, it is desirable that at least an outline of the subject should be presented to Sixth Form boys. Mathematical considerations will necessarily be confined to the few boys of the Sixth Form who are specializing in mathematics and physics, and if these are going on to the university, the subject should be taken up seriously, though certain of the mathematical aspects of the "general" theory are much too difficult for inclusion in a school course and, indeed, form a tough morsel at the university itself.

The real trouble with beginners is their reluctance to throw on the scrap-heap certain ideas which hitherto have seemed to them logical necessities of thought—space and time as independent things; gravitation as a "force", and a force of attraction at that; the æther as something with a great density, even a calculable density; mass and energy as separate and distinct things. Until a boy is willing to surrender his old ideas, and to set to work anew, he will undoubtedly feel hostile to the new subject. He must give up the old notion that space bears no responsibility for anything that may happen in it.

The best books for beginners are Professor Rice's and Mr. Durell's, both simply written and easily mastered in a very short time. These may be followed by the greater part of Professor Einstein's own elementary book (*The Theory of Relativity*), a little book of 128 pages containing the essence of the whole subject, put in as simple a form as the difficulties permit. Under guidance, selections from Professor Nunn's and Professor Eddington's books may then be read. Nunn's book is a model from the teacher's point of view, but the mathematics of the latter part of it is beyond the reach of most school boys. The easier parts of Eddington's book should be read by every boy who intends to take up a university course in mathematics or physics.

The following is an outline, with occasional comments, of a course of lecture-lessons given, with considerable success, to a class of Sixth Form boys who had been well grounded in mathematics and physics.

Before Einstein

The following ground must be covered (much of it will, of course, be revision), before the subject of relativity can be understood.

Relative position and relative motion. Nothing in absolute rest. Fallacious inferences from sense-data. A New Zealander says England is " down under ": justification. The baffling complexity of astronomical movements: planetary orbits—loops, cycloids, circles, or ellipses, and why. The lunar orbit round the sun: why a looped or sinuous path is not possible. Absolute and relative space and time.

Newtonian mechanics. Laws of motion; inertia. Study of a falling body in a lift ascending and descending with uniform and with accelerated motion.

Newtonian gravitation. Newton's deductions from Kepler's laws. His own law of gravitation and how he was led to formulate it and how he verified it. Any convincing reason why the attraction falls off *exactly* as the square of the distance?

Simple harmonic motion. Study of the pendulum. Variation of g. Centripetal acceleration and tangential force. Extent of increase of earth's rotation to make g ineffective.

Wave-motion and the æther. Characteristics of all waves: resistance, persistence, over-shooting the mark. Transfer and conversion of energy in wave. Water waves and sound waves compared. Interference: water shadows and sound shadows.

Æther waves, artificial and natural. Electrons as charges of electricity. Surplus and deficit of electrons in discharge of Leyden jar; hence over-shooting the mark and train of oscillations; analogy with weakening pendulum. Visualization of electromagnetic waves. The æther as a wave carrier; how its properties are deduced.

Light. Velocity and how determined; inference from its equality to the ratio of static and electromagnetic units. The visible and invisible spectrum. Inference that actinic waves, light waves, heat waves, and electric waves are of the same nature.

The eye and the ear. Their remarkable limitations.

The phenomenon of aberration. Inference: a stationary æther, which is therefore a possible reference frame for all measurements.

The Michelson-Morley experiment. Inference: æther not stationary but accompanies the earth in its travels.

These two inferences obviously contradictory. Attempts to reconcile them: (1) by Fitzgerald and Lorentz, (2) by Einstein.

The Fitzgerald-Lorentz contraction hypothesis. Professor Eddington's swimmer illustration, and the simple evaluation of the fundamentally important compensation factor $\sqrt{1 - \frac{v^2}{c^2}}$. Fitzgerald's suggestion of a physical contraction, to that extent, of the arm of the Michelson-Morley apparatus; the contradictory inferences thus reconciled. Theoretical confirmation by Lorentz. Why the contraction is impossible of detection. The contraction hypothesis quite plausible on the assumption of the electrical theory of matter.

The Lorentz transformation. Co-ordinate reference frames. Change of origin. Assume one frame fixed, and a second moving in the direction of the x axis. Then $x = x' + vt$, $y = y'$, $z = z'$, $t = t'$. The Lorentz transformation of these equations, by introducing the compensation factor into the first, and by modifying the fourth consequentially. Then $x = \dfrac{x' + vt}{\sqrt{1 - \dfrac{v^2}{c^2}}}$, &c.

The consequential composition of velocities, not $V = v_1 + v_2$, but $V = \dfrac{v_1 + v_2}{\sqrt{1 - \dfrac{v_1 v_2}{c_2}}}$.

(The whole of the preceding formed Einstein's jumping-off ground, and he now comes on the scene.)

Einstein and Afterwards

Einstein disliked the idea of a *physical* contraction, and he sought a more acceptable solution. He maintained that *length* was merely a relation between a particular object and a particular observer, and he denied the independence of space and time.

The Special Theory of Relativity

Einstein's "special" theory is, at bottom, a new interpretation of the contraction (compensation) factor. The theory involves two principles: (1) All reference frames in relative uniform motion are on a par; (2) The velocity of light in vacuo is invariable, and is independent of the motion of the body emitting the light; and any observer measuring the velocity must always get the same result, irrespective of his own motion (if uniform and rectilinear) with regard to the body emitting the light.

Each of the two principles seems to be true, although, as regards the second, there is no experiment to prove the invariable concentricity of light-waves with respect to the observer.

But the two principles seem to clash. Einstein makes them consistent by adopting a new criterion of simultaneity.

Criterion of Simultaneity. How determined. It follows that a metre scale moving relatively to a fixed scale reduces to $\sqrt{1 - \frac{v^2}{c^2}}$ of itself, and that a seconds-ticking clock in relative motion seems to run slow, the time between successive seconds being increased by $1/\sqrt{1 - \frac{v^2}{c^2}}$ sec. Planes of simultaneity. No clear cut between past and future. (See the last section but one of this chapter.)

It should be noted that the special theory provides an exact explanation of the effect of moving water on the velocity of light, as determined by Fizeau's experimental verification of Fresnel's hypothesis.

The General Theory of Relativity

1. *Gravitation and acceleration: preliminary considerations.*— We say that a stone falls to the ground because of the existence of a force of gravitation, inherent in the earth's mass, which attracts the stone towards the earth's centre. But this is only part of the story. The stone's path is more accurately determined by supposing the stone to be acted on simultaneously by two forces—a gravitational force of attraction towards the earth's centre, and a tangential (" centrifugal ") force arising from the earth's rotation. It is only because the rotation is comparatively slow that the hypothesis of attraction towards the earth's centre gives a fairly correct account of the fall of the stone.

One of the first problems given to beginners in astronomy is to prove that the effect of the earth's rotation is to decrease the weight of a body at the equator by about 1/289 of the whole. If the earth rotated $\sqrt{289}$ (= 17) times as fast as it now does, the two forces would just balance, the " weight " of the body would be reduced to nil, and there would certainly be no tendency for the body to " fall " towards the centre of

the earth; and we should be driven to invent an entirely new hypothesis to explain the neutral motion of the body. If the earth rotated faster still, the motion of the body would be such that we should probably invent an hypothesis to the effect that the motion is due to a gravitational force of *repulsion* inherent in the earth.

Obviously, then, it is easy to confuse gravitational attraction with acceleration arising from the earth's rotation. In fact, it is impossible to distinguish between the effects of gravitational attraction and the effects of acceleration of any kind whatever. Every aeroplane pilot knows this only too well. It is impossible to devise any instrument to show the direction of the vertical in an aeroplane, since the acceleration of the aeroplane produces, on any instrument, effects which are indistinguishable from those of gravity.

Gravitational " fields of force " are therefore really illusions. The apparent " force " arises solely from acceleration, and we are bound to conclude that there is no other kind of gravitational force at all.

The term " acceleration " is, of course, used in its wider sense. It may arise not only from a change in the amount of a velocity, but also from a *change in the direction* of the velocity. For instance, a motor-cyclist riding in a circle at a uniform speed of 60 miles an hour will be the subject of an acceleration towards the centre of the circle. He knows that the apparent force as produced is just as real in its effect as gravitation, and that he must, to save himself from falling as a result of its influence, incline to the vertical plane of his machine.

It is of little use to proceed with the general theory of relativity until a boy sees clearly that gravitation is merely an effect of acceleration. An admirable handling of the subject may be found in a lecture by Professor Brodetsky, reproduced in the *Mathematical Gazette* for July, 1928.

2. *Artificial Gravitational Fields.*—How they may be created and destroyed. Gravitational mass and inertial mass; hypothesis of the electromagnetic origin of matter. Is gravitation identical with inertia?

3. *Principle of Equivalence.*—It is impossible to distinguish between (1) a gravitational field of force, and (2) an artificial field of force resulting from accelerating a reference-frame. Illustration: an observer anchored in a room isolated in space, travelling with accelerated velocity in any direction; his inferences from the happenings in the room.

4. *The Four-dimensional Continuum.*—The union of space and time into " space-time ". The actual cause of gravitation had never been discovered, and Einstein asked himself if gravitation might not be merely some fundamental property of space-time. There is only one space-time, but this may be divided up into indefinitely numerous systems of space and time. We each have a space and time of our own, but we cannot divide space-time into space and time separately in the absolute sense. Every mode of division has a time-like aspect and a space-like aspect. Natural phenomena are not concerned with space and time separately. Our *where* and *when* are always associated, even in the headings of our letters. Space-time considered as a four-dimensional continuum. The fourth dimension, t. The " flat-land " analogy may mislead, though the surface of a sphere is useful to illustrate a two-dimensional limited but unbounded space. Imaginary cinematograph film of all the events of a man's life. (See the section on the Relativity of Simultaneity, *infra*.)

5. *Events and Intervals.*—Geometrical interpretation of the factor $\sqrt{-1}$. (See the section on the Relativity of Simultaneity.) The " interval " an absolute quantity, a unique distance between " events ". The general interpretation of the equation $ds^2 = - dx^2 - dy^2 = dz^2 + dt^2$.

6. *Curvature of the Continuum.*—Why the geometry of a gravitational field is non-Euclidean. " Curvature " of such a field indicates, primarily, deviation from Euclidean geometry. The curvature of the continuum cannot be visualized, but the curvature of light-rays crossing an accelerating lift is a useful analogy: this curvature is very slight because of the great velocity of light. " Curvature " is just a convenient term for a group of mathematical expressions analogous to those similar expres-

sions which in the geometry of surfaces do actually represent curvature. Sometimes we speak of a "warped" space-time or of a "distortion" of space-time, but neither term is any better than the term "curvature" for conveying to the mind any sort of picture of the thing concealed in the mathematical expressions.

7. "*World lines*" as (1) geodesics between two events in space-time; (2) tracks of particles in a gravitational field; (3) world-history. ("World" an ambiguous term.)

8. *Gravitation.*—The mathematics of the subject is much too difficult, and even advanced pupils must be content to understand the data with which Einstein began his analysis, and to understand, in a *general* way, the significance of his final result. Do not obscure main ideas by befogging them with symbols. The pupils may be told that it all works out to this—that gravitation is some kind of curvature or distortion of space-time due to the presence of matter; and that this distortion is a necessary inference (of which no one questions the validity) from mathematical analysis, but that *it cannot be visualized.* Einstein's theory of gravitation is not a theory that enables us to picture a sort of working mathematical model, like Newton's model; it is a *mathematical* theory.—Give some idea of the general equation of a two-dimensional surface, and of the possible extension to four-dimensional space-time. The actual gravitational "field" resulting from Einstein's analysis is, at bottom, extraordinarily like that enunciated by Newton. For all practical purposes, the inverse square law is produced by the relativity theory, but the form of the law is quite different; the new law is

$$ds^2 = -\frac{1}{\gamma}dr^2 - r^2d\theta^2 + \gamma dt^2.$$

Its *appearance* is altogether different from that of Newton's simple law, but, applied to particular cases, it gives almost identical results. Its great gain over the old law is that it accounts exactly for the few discrepancies that the old law could not be made to cover.

The only possible reason for preferring the old law to the new is that it is much simpler in form. There is no defence for such preference, unless it be sentiment. We are apt to put a child-like faith in clear mind-pictures, and to distrust mathematical analysis. But if the mathematical analysis is based on data which nobody questions, and if the logic of the analysis is irrefutable, how can final results be assailed, even though the mind cannot indulge its natural desire for picture-making? The real trouble with relativity is that few of us are good enough mathematicians to follow out the logic of Einstein's analysis, and we need not be ashamed to say so.

Tests of the New Law of Gravitation

The tests are three in number, and all are easily explained.

1. Rotation of orbit of Mercury.—Confirmatory of new law.
2. Deflection of light-rays in a gravitational field.—Confirmatory of new law.
3. Displacement of spectrum lines towards the red.—Recent work confirmatory of new law.

The pupils should know that the effect of these successful tests was so great that relativity has since received a world-wide acceptance.

The Relativity of Simultaneity

The following is a complete outline of a lecture-lesson on one aspect of relativity. It is complete enough for a well-trained Sixth Form boy to follow without help.

Since all bodies are in a state of motion, the separate consideration of space and time must inevitably involve us in logical contradiction, and this is really the basic fact on which the whole fabric of relativity is constructed. But relativity does not mix up space and time into a sort of compound, the constituents of which lose their individuality and disappear. The four-dimensional space-time continuum is *not* suggestive of a new form

of fruit-cake, or anything else so absurd. The essence of the whole thing is that four variables are necessary to define the position of a given body at any given moment, three in space and one in time. All unconsciously we adopt the procedure of associating space and time every day of our lives when we begin a letter. We say *where* we are writing and *when*.

All this seems very simple. Then wherein lies the difficulty, if space and time seem so easily separable? The difficulty lies in the fact that space and time can *not* be separated from each other in any absolute way. The particular mode of separation depends on the particular observer, for, when two observers are in relative motion, events which appear to be simultaneous to one of them do not appear to be simultaneous to the other. It is useless to try to visualize the fourfold continuum, since it is merely an abstract conception, resulting from mathematical considerations.

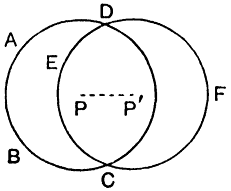


Fig. 7

When we say that we "see", we mean that the news of more or less distant happenings is reaching us by means of light signals which travel with a constant velocity c. Hence, to an observer P, events will be simultaneous which are on the circumferential light-wave of which he is the centre, e.g. the events A, B, C, and D. (Fig. 7.) But while P has one conception of simultaneity, a second observer P′, who moves out from P to P′ while the wave is advancing from P, will have another. For it is a fundamental principle of relativity that the velocity of light is constant to P′ as well as to P, and events which are simultaneous to the former must therefore be on another circumferential wave-front DECF with himself as centre. Clearly, then, A, B, C, and D cannot be simultaneous for P′. If, as relativity demands, as experiments suggest, and as we feel bound to admit, the velocity of light with respect to observers in relative (unaccelerated) motion is invariably c for all, we have to abandon our old notion of absolute simultaneity.

Einstein's criterion of simultaneity is this. He measures off

a length AB on a railway embankment, and places an observer, provided with two mirrors at 90°, at the exact mid-point M. If light flashes emitted from A and B are perceived in the two mirrors by the observer at the same time, then the flashes must have been emitted simultaneously. (Fig. 8.)

He now considers a train moving with a constant velocity v, and we are to imagine that any event which takes place along the embankment also takes place at some particular point on the train. The criterion of simultaneity is to be applied with respect to the train in exactly the same way as with respect to the embankment. Einstein now asks if the lamp flashes which are simultaneous with respect to the embankment are also simultaneous with respect to the train.

The events A and B correspond to positions A′ and B′ on

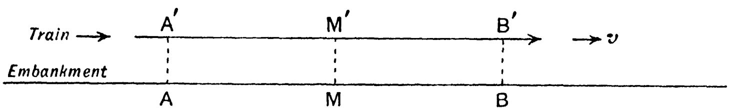


Fig. 8

the train. Let M′, the mid-point of A′B′, be the position of the observer on the travelling train. When the flashes occur (as judged from the embankment), M′ coincides with M, but is moving with the velocity v.

But not only is the observer at M′ hastening towards the beam of light coming from B, he is also riding on ahead of the beam coming from A. Hence he will see the beam of light emitted from B earlier than he will see that emitted from A, not because the beam has changed its velocity but because it has a shorter distance to travel in order to meet him. He will thus conclude that the flash B took place earlier than the flash A. Hence events which are simultaneous with reference to the embankment are not simultaneous with respect to the train, and vice versa. Thus every co-ordinate reference system must have its own particular time; the idea of simultaneity is only a relative idea; "half-past one" has no absolute significance.

A general physical law can be so expressed that it is transformed into a law of the same form when, instead of the space-time variables x, y, z, t, of the original co-ordinate system (K), we introduce space-time variables x', y', z', t', of a new co-ordinate system (K_1). The relation between these two sets of magnitudes is given by the Lorentz transformation.

We usually speak of " space " as three-dimensional, and we talk of length, breadth, and depth (or height). Are we justified in looking upon " time " as a fourth dimension, and of treating t as co-ordinate with x, y, and z?

If a common house-fly is moving about a room, its position at any instant is determined by its distance from each of two adjacent walls and the floor, in other words by x, y, and z in that particular co-ordinate system. But the fly may move slowly or quickly, and to know all about the motion of the fly we must know the velocity with which it moves from point to point. But velocity is a term which involves the notion of time as well as space, and thus we must consider t as well as x, y, and z. Now *all* bodies are in motion; nothing is at absolute rest. If therefore we try to dissociate space and time, confusion will be inevitable. It is safer to speak of them together, and to speak of them as " space-time ".

Relativity does not deal with four-dimensional " space ": it is not concerned with finding means for " ghosts " to get into and out of an hermetically sealed room! But it does deal with the four-dimensional continuum, space-time, which is a very different thing.

The three co-ordinate x, y, and z planes are usually represented at right angles to one another. The " up-and-down " direction is clearly at right angles to the " right-and-left " direction, and to the " backwards-and-forwards " direction; and so reciprocally with all three. These three directions seem to map out the whole of space as we know it, and it is clearly impossible to find a fourth direction at right angles to the other three. And relativity does not really demand this. Nevertheless, in dealing with the four-dimensional continuum, in which one of the dimensions is time, it is perfectly legitimate,

within certain limits and under certain restrictions, to make time and space interchangeable. In this way we may easily show that events which are simultaneous in one system are not necessarily simultaneous in another.

In visualizing any problem in which the relative motion of two systems alone is concerned, we usually, for convenience, choose the axis of x for the direction of motion, and take the axes of y and z, arbitrarily, at right angles thereto. But in dealing with such a problem, we can quite well do without one of the axes y or z, in which no relative motion in space is taking place, and so find room for the axis of time. It might be thought that we could do without both y and z, but from what follows it will be seen that the retention of one is necessary.

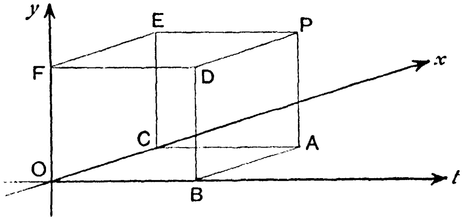


Fig. 9

We will confine all space movements to space of two dimensions, namely, to the vertical plane xy, x being the axis of relative space-motion of the two systems to be considered. The axis of x is represented as a horizontal, and the axis of y as a vertical, in the plane xy. The flow of time t is represented by the discarded z axis, this t axis being, of course, at right angles to the xy plane, and, in the figure (fig. 9), running horizontally to the right.

Any point P projected on the three planes xy, xt, yt, represents an event, (1) at the abscissa distance OC, giving its position relative to O along the axis of x; (2) at the distance OB, giving the time of its occurrence along the axis of t; and (3) giving its position F along the axis of y and above the horizontal plane xt.

The two-dimensional plane *xy* is Euclidean, but the three-dimensional space-time *xyt* is not Euclidean; neither is the plane *xt* Euclidean. For the *t* ordinate represents *time*; and in order that time, regarded as a fourth dimension, may be brought within a Euclidean system, it is necessary, as we shall see, to multiply it by the imaginary quantity $\sqrt{-1}$. We must therefore determine how, geometrically, the three-dimensional *xyt* space-time may be converted into Euclidean form.

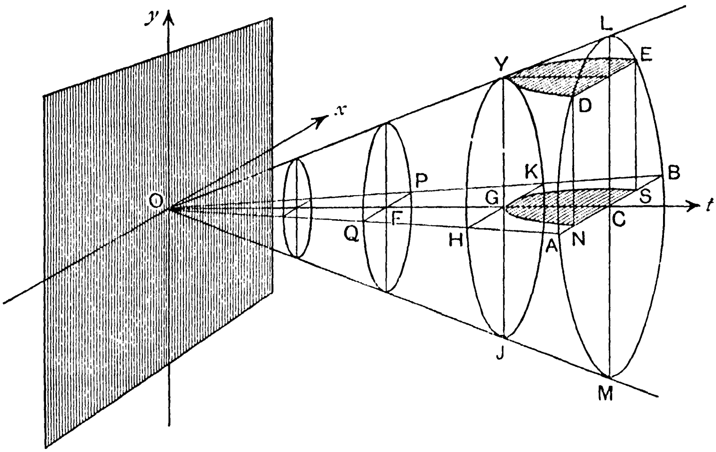


Fig. 10

Suppose that, at the place and time defined by the position O (fig. 10), a luminous flash takes place. Then as time progresses along the axis *t*, the light emitted will proceed outwardly from O as a spherically expanding shell. But as we have discarded one of the dimensions of space, and have therefore only two dimensions left, namely, a plane, only a plane section of this sphere can be spatially represented. This section is, of course, a circle, and as the space-plane moves along the *t* axis, the successive circles get larger and larger with the expanding light-shell. It thus comes about that, in our three-dimensional space-time figure, we have a light-cone with its apex at the origin and the axis of *t* for its own axis. We may pro-

visionally regard the xy space-plane as fixed relatively to ourselves, the progress of time being represented by that plane sliding uniformly along the t axis.

From Einstein's criterion of simultaneity it follows that events on the circumference of, say, the circle PQ would be simultaneous; for if new flashes of light were emitted at P and Q at the same instant of time, since the plane xy contains both the resulting light-waves they would clearly intercept at a point F on the t axis; symmetry shows that the conditions of simultaneity are fulfilled.

Geometrically considered, since the plane xy moves freely parallel to itself, the successive circles may be supposed to represent *planes of simultaneity* for the xyt system to which they relate. We have reduced our space world to the relatively fixed two-dimensional plane xy, and every plane parallel to xy represents, in time, a plane of simultaneity for that system.

So far, we have considered a relatively fixed reference system. Relatively, the observer does not move in space at all, not even along the axis of x. He and his reference system K simply move down the stream of time. It is as if he remained seated in his laboratory O, and the successive circles represented successive seconds, successive days, or successive periods of *some* kind. The points on the circumference of a circle represent simultaneous events for the observer at the centre. There is movement in time only.

But suppose there is movement in space also. At the instant the flash is emitted from O, let a point move with uniform velocity along the axis of x. Compared with the velocity c of light along the axis of t, the velocity of the point along the space axis x will, in all ordinary circumstances, be almost insignificant, but that does not affect the argument. The problem is: will the planes of simultaneity in the moving system K_1 be the same as, or will they be different from, those in the relatively fixed system K?

Let AB (fig. 10) be the horizontal diameter of the circle LAMB; OAB is thus the horizontal medial section of the cone. Through any chord DE parallel to AB, cut off a section DYE

of the cone, parallel to OAB. Obviously DYE is an hypeibola. Project this hyperbola to NGS in the plane OAB, and draw the tangent HK. This tangent is, of course, the diameter of another circle in a plane of simultaneity, viz. YHJK.

Fig. 11 is the horizontal Oxt plane from fig. 10. The apex of the cone is shown as a right angle, for mathematical simplicity, but the general argument is unaffected. HK is the projection of the plane of simultaneity YHJK (fig. 10) upon the Oxt plane, and is of course identical with the x axis which has moved down the stream of time t. Let Ot_1 represent the path of the point in the moving system. Whilst it moves along the

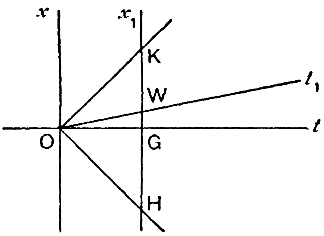


Fig. 11

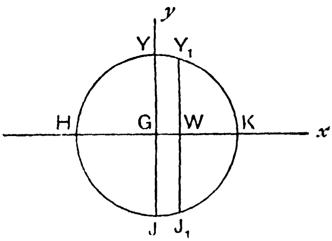


Fig. 12

axis of t from O to G with the velocity of light, it moves in space along the axis of x from G to W.

Fig. 12 represents the section of the light cone through the plane of simultaneity HK. In the fixed system, GH = GK = GY = GJ, so that the velocity of light in both directions along the x axis, and in both along the y axis (hitherto ignored) is the same, and the condition of constancy, c, is thus complied with. But if light from W in the moving system reaches H and K at the same time, the velocity in the one case is obviously greater than c, and in the other less; moreover, since WY_1 or WJ_1 is less than GY or GJ, the velocity along WY_1 or WJ_1 is less than c. Thus the condition of constancy is not complied with, and it therefore follows that planes of simultaneity for the moving system are not identical with those for the fixed system.

We therefore have to adjust the co-ordinates for the moving

system in such a way that an observer in it cannot detect any variation in the normal velocity of light c.

Fig. 13 is the greater part of fig. 11 repeated, with the addition of the hyperbola from fig. 10.

The sides of the cone cut off equal intercepts from the tangent at G_1, that is, $G_1H_1 = G_1K_1$. Hence the velocity of light is the same in both these directions of the moving system.

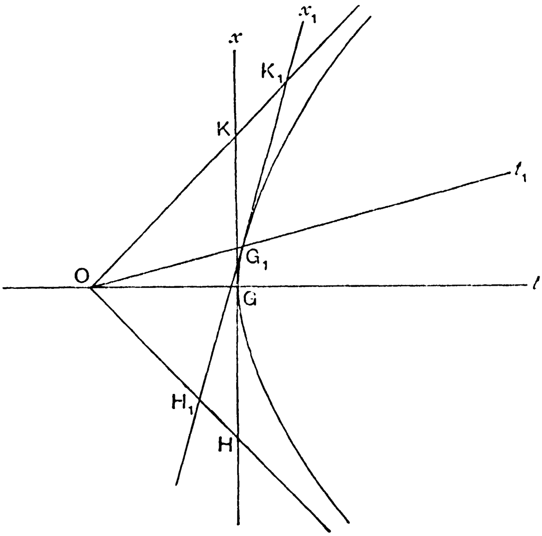


Fig. 13

Apparently, then, this new line x_1 may be regarded as the x axis of the moving system. It is a projection of the x_1y plane, and it slides down Ot_1 parallel to itself. It is a projection of a plane of simultaneity in the moving system.

Thus we appear to have found a co-ordinate system x_1t_1 for a point moving relatively to the fixed xt system. There has been motion in time and in one direction in space. Using only one direction in space has enabled us to simplify the argument, which, however, may be considered sufficiently general.

It is now necessary to see if, in the moving x_1t_1 system,

the principle of the constancy of the velocity of light is satisfied.

From fig. 10 we see that all points on the hyperbola DYE are equidistant from the xt plane. Hence in fig. 13 the distances from the points G and G_1 along the y axis to the conical surface are equal. Thus the condition that the velocity of light travelling at right angles to the direction of motion shall be constant, and the same for both systems, is satisfied if G occupies its position on the x axis of the fixed system, and G_1 its position on the x_1 axis of the moving system, at the same instant.

But, at first sight, this equality does not seem to apply to the direction of motion itself. For, in fig. 13, KH is the projection of a circle, and K_1H_1 of an ellipse; and G_1H_1 or G_1K_1 is obviously longer than GH or GK. But since $G_1K_1 = G_1H_1$, the velocity seems to be equal in both directions, though greater than in the fixed system; and it might be thought that, for the moving system, the light wave-front due to the flash at O is elliptical. But this is impossible.

The key to the difficulty is to be found in the fact that the xt plane (fig. 13) is not Euclidean. Physical lengths measured along a line involving time are not those measured on the paper. But if we multiply such lengths by $\sqrt{-1}$ they reduce to Euclidean lengths, and we then have the ordinary Euclidean geometry. In the case under consideration, G_1H_1 or G_1K_1 reduces to GH or GK, and our supposed ellipse in the moving system reduces to the circle in the fixed system. This will be demonstrated directly. The principle of the constancy of the velocity of light thus holds.

Thus, in the moving system, the apparently elliptical form of the expanding plane of simultaneity becomes truly circular when transformed by means of the multiplier $\sqrt{-1}$.

Some indications of the formal demonstrations may be given.

We begin by adopting a simple geometrical device which may be spoken of as the $\sqrt{-1}$ transformation.

Fig. 14 shows a length x compounded with a time t. The hypotenuse PR of the triangle PQR is obviously $\sqrt{x^2 + t^2}$.

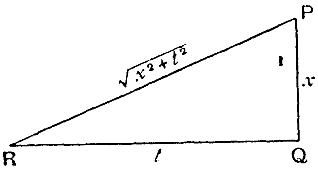


Fig. 14

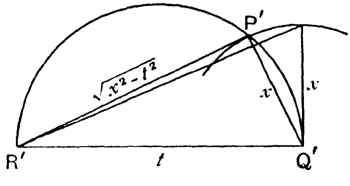


Fig. 15

But if we multiply t by $\sqrt{-1}$, then $\sqrt{x^2 + t^2}$ is transformed to $\sqrt{x^2 - t^2}$. Fig. 15 shows the geometrical construction for obtaining P′R′ of this value. (P′ is the intersection of a circle on R′Q′ as diameter, and of a circle with centre Q′ and radius x.)* Note that the general direction of RP is only very slightly modified when transformed to R′P′.

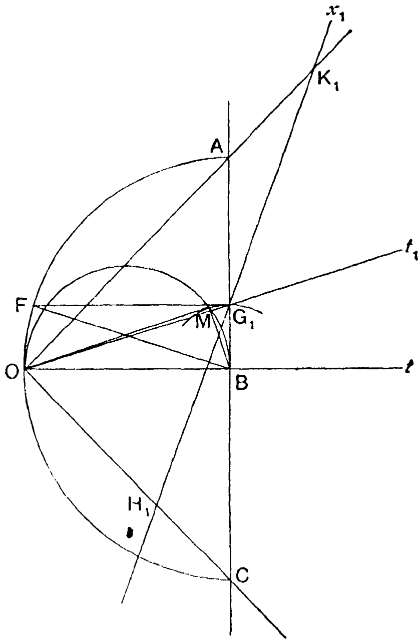


Fig. 16

We proceed to indicate the steps of the main demonstration.

In fig. 16, the points O, G_1, H_1, K_1 are as in fig. 13. Through G_1 draw ABC at right angles to Ot. With centre B and radius BA or BC draw the semicircle COA, and draw the perpendicular

* It might be argued that the figure suggests $\sqrt{t^2 - x^2}$ rather than $\sqrt{x^2 - t^2}$, and, in point of fact, t actually is usually very much greater than x. But the important thing here is difference of sign. By making t negative, we can conveniently keep x, y, and z positive.

G_1F to meet it. This ordinate G_1F is obviously equal to the semi-minor diameter of the ellipse (cf. WY_1 in fig. 12) which has been swung round on G_1 from the vertical into the horizontal plane.

To the triangle OBG_1 apply the $\sqrt{-1}$ construction of fig. 15, so that OM corresponds to R′P′ in that figure; OM is thus the real length of OG_1. But since H_1OK_1 is a right-angled triangle, and G_1 is the mid-point of the hypotenuse, $G_1K_1 = G_1O = G_1H_1$. Hence OM is the real length of G_1K_1 and G_1H_1.

Again, in the triangles OBM and FBG_1, BO = BF, BM = BG_1, and the angles OMB and FG_1B are right angles. Hence the triangles are congruent, and FG_1 = OM, the semi-minor diameter of the ellipse. This semi-minor diameter is therefore equal to the transformed and real lengths of the semi-major diameters G_1H_1 and G_1K_1. In other words, the apparent ellipse is a circle, and the velocity of light is therefore constant in all directions.—Q. E. D.

The apparently elliptical form becomes a circle when the $\sqrt{-1}$ transformation is carried out. The circle is necessary because we have to obtain conditions complying with the principle of the constancy of the velocity of light, but the circle is obtainable only by treating t differently from x, y, and z. Thus we say that the space-time represented in our figures is not strictly Euclidean.

Since a plane of simultaneity in the moving x_1 system (K_1) is not parallel to, but inclined to, a plane of simultaneity in the x system (K), we see that events which are simultaneous in one system are not simultaneous when considered as happening in a system in motion relatively to it.

The measurement disclosing the shortening of a body in a system K_1 must be made, not in the plane of simultaneity K_1, but in the plane of simultaneity K, and vice versa. The shortening is in the measurement of the body in motion, made from the body supposed to be at rest; it is manifest only when the movement of one body is made from the standpoint of another body moving relatively to it. Of course it is a reciprocal

phenomenon. From the point of view of the physicist chained to his own system, which he therefore considers at rest, and making his observations from that system, his measurements of bodies moving relatively to him reveal a shortening which to him seems real.

From some point in the intersecting line of two planes of simultaneity in two relatively moving systems, let two lines be drawn, one in each plane. The other ends of the lines will, in general, occupy different positions in time. Thus while we can compare one end of each of the two lines at some given instant, we cannot compare the other ends at the same instant. The two comparisons are not simultaneous events. Instantaneous comparisons in relatively moving systems are impossible because of our dependence on light signals, and thus the relatively moving thing always appears to be shortened.

This shortening is not, according to relativity, a physical shortening. It is an *apparent* shortening for an observer chained to some other system in relative motion.

It is important for pupils to grasp the principle that two observers S and S_1 in their respective systems K and K_1 are affected in precisely the same way. The arguments throughout are reciprocal.

Fig. 17 is a slight modification of fig. 13.

Ox and Ot are the space and time directions, respectively, of the observer S; and Ox_1 and Ot_1 of S_1. OL and OL_1 are the light lines representing the section of the light-cone made by the xt plane. Let OW and OG be equal and represent unit distances in space and time, respectively, in the system of S. In the system of S_1, $OW_1 = OG_1$, where the units are obviously a little greater, depending on the observer's own reckoning. $OW_1K_1G_1$ is evidently a rhombus.

S will consider his own space-time reference system to consist of a framework of squares, but will consider the reference system of S_1 to consist of a framework of rhombuses. On the other hand, S_1 will consider his own reference system to consist of squares, and that of S to consist of rhombuses. For each the other's framework of squares will be distorted.

" Shape " is something which each himself puts into nature. For each the partitions of his own framework are unit distance apart in space and time, according to his own reckoning. But although the two disagree about lengths and durations, they do agree about the constancy of the velocity of light. (Figs. 18, 19.)

The farther K_1 is taken along OL, the more elongated the rhombus, and the larger the unit divisions OW_1 and OG_1. The

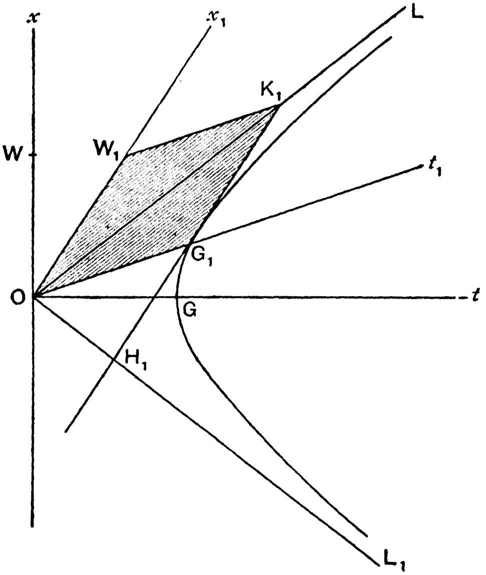


Fig. 17

line Ot_1 then lies nearer and nearer the light line OL. Such an elongated framework would seem by S to be made by S_1 if the latter were travelling at a very great velocity. In the limit, when the velocity reaches that of light, both the space unit and the time unit become infinite; and S will conclude that the length of every object in S_1's system has been reduced to zero, and that all events in S_1's system take place " in no time ". This is really an exaggerated way of saying that the velocity of light is a limiting velocity.

We may conclude with an illustration, but the pupils must remember that all analogies are likely to mislead.

Imagine a continuous film record of the whole of a man's life to be taken. (In practice, of course, cinematographic " continuity " is impossible, for the pictures on a film are not pictures of events at consecutive point-instants. Gaps are inevitable, for every picture takes an appreciable time for the making. Ordinarily only about sixteen pictures a second are taken, and clearly a great deal may happen that the film cannot record.) Imagine the film to take in a background of sufficient expanse to include every movement, no matter how extensive, of the man during the whole of his life. Now let the

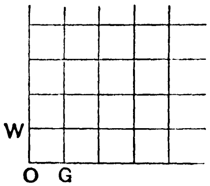


Fig. 18

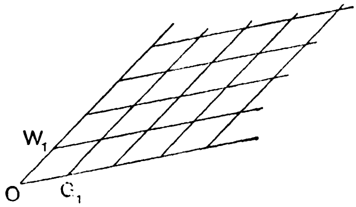


Fig. 19

individual pictures be separated and piled in a block (conceivable, though not imaginable, because the number is infinite). We have a three-dimensional (xyt) space-time record of the man's life. Each separate section of the film is, for the man, a record of simultaneous events at a particular moment. If the film were reproduced on a screen, we could lengthen or shorten the time component of the space-time continuum merely by varying the speed of turning the machine. Could we but see the whole of the successive pictures in the three-dimensional block simultaneously, that is, all at the same instant, as completely and fully as we can see an ordinary object at rest, then we should have some idea of how a man might be represented in four-dimensional space-time.

Now let the whole block of superimposed films be fused into a single block, the separate laminæ, as such, all disappearing. And let the block be cut into laminæ again, but by parallel

planes in a direction oblique to the former. The new films may be regarded as representing the background of a second person's life (the distortion of the original pictures will, for this purpose, be immaterial), and each film will again be a record of simultaneous events for a particular instant. But the new films will intersect the old. Hence what was simultaneity for the first person will not necessarily be simultaneity for the second, except where the planes intersect.

Unsolved Relativity Problems

Intelligent boys may profitably be given some idea of the problems engaging relativists, astronomers, and others at the present time:

1. The hypothesis of the electromagnetic origin of matter.
2. Gravitation and electricity: attempts at unification.
3. Is there an æther? Relativity asserts that the four-dimensional continuum has a *structure*. Hence it cannot be the mere void of empty space, though relativists refuse to identify it with a Maxwell æther, subject to the laws of dynamics. We may perhaps consider the "universe" to refer to the continuum which includes all things visible, i.e. the stellar universe, the matter-containing universe, conceivably wholly within a limitless void.
4. The size of the stellar universe. Light takes a million light-years to reach us from the Andromeda nebula, and it is calculated that the universe may extend 20,000 to 100,000 times as far as this, i.e. its radius is about 10^{23} miles, and its circumference about 6×10^{23} miles. If radiated light remains within this universe, and travels round and round (as is thought to be the case), it completes the circuit in $6 \times 10^{23}/6 \times 10^{12}$ years, i.e. 10^{11} years, i.e. it goes round 10 times every billion years, travelling at the rate of 186,000 miles a second. If we could visualize this line, the curvature would seem so slight that even any billion miles of it would look absolutely straight.

It is an impressive fact that light travels round the earth

in $\frac{1}{7}$ of a second, and yet seems to require a hundred thousand million years to travel round the universe.

The pupils should know something of the method adopted for calculating the volume of space-time by measuring the density of the distribution of matter in space.

Try to give the boys some idea of the value of the evidence on which all these estimates are made, and what a large number of hypotheses, some of them highly speculative, are involved. Insist that we may be a very long way from the actual facts. *Urge caution.*

Another Warning

The astronomical model of the atom lends itself all too readily to picture-making, with the consequence that it inspires us with an almost royal confidence in its reality, a confidence which, though natural, is quite unwarranted. But Einstein's warped space-time defies all attempts to picture it, a fact which makes many people sceptical of the validity of the whole theory of Relativity. The scepticism in the second case is, however, as unwarranted as the over-confidence in the first. See Chap. XXXVI, §4.

CHAPTER XXXIII

The very Great and the very Small

When attempting to help a boy to form a clearer conception of the significance of very large numbers, say those concerning stellar distances or atomic magnitudes, it is essential for the teacher to eliminate from the problem every kind of avoidable complexity. To form a conception of a great number is quite difficult enough in itself, and to a boy the difficulty may prove insuperable. On one occasion I heard a teacher attacking our old friend the " light-year ", in favour of its new rival the " parsec ", simply on the ground that the latter made astro-

nomers' computations easier. Now the light-year is a perfectly well understood thing. In mechanics we often define distance as the product of velocity and time ($s = vt$), as every child knows; and we apply this self-same principle to the distance known as a light-year, the new unit being determined by the product of the velocity of light (miles per second) and the number of seconds in a year. But the parsec is the distance corresponding to the parallax of 1″, and a simple calculation shows that it is 3·26 times as long as the light-year; and this trigonometrical method of determining star distances compels the learner to think in terms of the semi-major axis of the earth's orbit. The complexity is entirely unnecessary in school work; it tends to obscure the main thing the boy is supposed to be thinking about.

Simple arithmetic tells the learner who knows that the velocity of light is 186,000 miles a second, that the length of the light-year is, approximately,

$$(186{,}000 \times 60 \times 60 \times 24 \times 365) \text{ miles, i.e. } 6 \times 10^{12} \text{ miles,}$$

or 6 billion miles. Thus, when the learner is told that *a Centauri* is 4 light-years distant, he knows that this means 24 billion miles; and that the 1,000,000 light-years representing the probable distance of the remoter nebulæ is a distance of 6×10^{18} (six trillion) miles. Or, he may be told that the mass of the H atom is $1{\cdot}66 \times 10^{-24}$ grams, when he sees at once that 10^{24} H atoms together must weight $1\frac{2}{3}$ grams.

But are these vast numbers anything more than mere words to the boy? What does a quadrillion signify to him? or even a trillion or a billion? or even a million? Is it of any use to try to make the boy realize the significance of such numbers? or just to leave them as mere words? or not to mention them at all and merely to give some such illustration as Kelvin's earth-sized sphere full of cricket-balls?

I have tried the experiment of giving to boys such illustrations as these: (1) the number of molecules in 1 c. c. of gas is about 200 trillions (2×10^{20}), a number equal to the number of grains of fine sand, 70,000 to the cubic inch, in a

layer 1 foot deep, covering the whole surface of England and Wales; (2) the number of molecules in a single drop of water is about 1700 trillions ($1 \cdot 7 \times 10^{21}$), a number just about equal to the number of drops of water in a layer $7\frac{1}{2}$ inches deep completely covering a sphere the size of the earth.—But I have always found that such illustrations merely give rise to vague wonderment. The pupil himself *makes no personal effort* to realize the magnitude of the numbers; and this is fatal.

Such an effort is indispensable. The best plan, perhaps, is to make the pupil first consider carefully the magnitude of a million, then of a billion, a trillion, a quadrillion, successively (10^6, 10^{12}, 10^{18}, 10^{24}). For instance, an ordinary watch ticks 5 times a second or 1000 times in about 3 minutes, or a million times in about 2 days and 2 nights. Let this fact be assimilated as a basic fact, first. Now let the boy think about a billion. Evidently, a watch would take (for the present purpose, all the underlying assumptions may be accepted) about 6000 years to tick a billion times (2 days $\times$ 10^6), so that if a watch had started to tick at the time King Solomon was building the Jewish temple, it would not yet have ticked *half* a billion times! Now proceed to a trillion, and then to a quadrillion. Evidently the watch would take 6000 million years to tick a trillion times, and 6000 billion years to tick a quadrillion times.—An approach of this kind to the subject does not take long, and a boy fond of arithmetic may be encouraged to invent illustrations of his own. It is worth while. It is worth one's own while, if the attempt has never been made before. It is, indeed, hard to realize the significance of the statement that light-waves tap the retina of the eye billions of times a second. Yet how are we to escape accepting this frequency if we accept the measured velocity of light and the measured length of light-waves? Impress upon the boys the fact that the inference is inescapable.

The description of the manufacture of such a thing as a diffraction grating with lines ruled 20,000 to the inch, or of Dr. J. W. Beams' mechanical production of light flashes of

only 10^{-7} second duration, serve to impress pupils with the sense of reality of small things.

Professor Haas, accepting De Sitter's suggestion as to the size of the universe, and the average density of matter in the universe, estimates the mass of the universe to be 10^{54} grams, and, since there are about 10^{24} electrons in a gram, there must be about 10^{78} electrons in the universe. Haas suggests (*The New Physics*, pp. 152–3) that in thought this number may quickly be arrived at by means of an exercise of this sort:

"It is well known that bacteria are peculiar in that they propagate by a process of division of the individuals. From one bacterium in the course of an hour, there result two bacteria by this splitting-up process, and after an interval of two hours there are four, and so on. Let us suppose we have a single bacterium in a glass of water, and that it has the thickness of about a thousandth of a millimetre and twice this length. It would thus be approximately a billionth part of a gram in weight, and made up from roughly a billion electrons. We shall further assume that in some way or other, sufficient nourishment can be supplied to ensure that reproduction is not adversely affected by lack of food. In such circumstances there would be present some 16 millions of bacteria after one day, i.e. 24 hours; at the end of the second day there would be 300 billions, and after 3 days about 500 trillions, which would already correspond to a weight of thousands of tons. In the course of the sixth day, the mass of the bacteria produced would exceed the mass of the earth; in the course of the seventh day, the mass of the sun; in the course of the tenth day, the weight of all the bacteria would attain to the total weight of the universe; and finally in the course of the eleventh day the number of all the bacteria that would have developed from the original one would be as large as the total number of electrons in the universe."*

It does not pay to spend much school time over this sort of

* The figures do not quite agree with recognized British estimates. See pp. 377–8.

thing; but it is useful to teach the boys *some* method of apprehending great numbers intelligently, if only in order that they may grasp the tremendous significance of such numbers.

Boys must understand that both stellar magnitudes and atomic magnitudes are, for the most part, *calculated* values and not directly measured values, and that the calculations are, in the main, based on inferential evidence, the inferences being drawn partly from known facts, partly from hypotheses. But converging evidence of different kinds justifies a feeling of confidence in the probability of the truth of the estimate. So much so is this the case, that the natural repugnance of the mind to accept statements which seem to be so contradictory of everyday experience, and therefore to "common sense", is overcome. Still, the *nature* of the evidence available must be borne in mind. So must the amazing nature of the results!

It is a curious and interesting fact that certain chemists of the old school demur to accepting the electron theory, solely on the ground of the utter insignificance of the size and mass of the electron. And yet they readily accept the atom and its estimated size and mass. Really, there is no appreciable difference in the *order* of the magnitudes. Approximately, it is just a question of 10^{24} and 10^{27}.

In their *Biology*, Professors Haldane and Huxley give an interesting table of comparative sizes. Here are a few of them (the numbers refer to grams):

Minm. wt. of universe	$1{\cdot}8 \times 10^{57}$	Ant	10^{-1}
Sun	2×10^{33}	Water flea	10^{-3}
Earth..	6×10^{27}	Tubercle bacillus ..	10^{-12}
Average man ..	10^5	Gene (hereditary factor)	10^{-17}
Mouse..	10^2	Water molecule	10^{-22}
Bee	10^0	Electron	10^{-27}

A Sixth Form boy may usefully memorize a few of such well-known magnitudes as the following, now generally regarded as having been calculated with acceptable accuracy:

Mass of an electron	$0{\cdot}9 \times 10^{-27}$ gm.
Mass of H atom	$1{\cdot}66 \times 10^{-24}$ gm.
Radius of K orbit of H	$5{\cdot}27 \times 10^{-9}$ cm.
Balmer frequency constant, B ..	$(3{\cdot}29 \times 10^{15})$ per second
Rydberg constant (wave-number), R	109677·69
Mols. in 1 c. c. of gas (N.T.P.) ..	$2{\cdot}8 \times 10^{19}$
Light year	(6×10^{12}) miles
Distance of remoter nebulæ	10^{6} light years $= (6 \times 10^{18})$ miles
Radius of stellar universe	10^{23} miles

As for microscopic magnifications, boys should be taught to calculate these for themselves.

CHAPTER XXXIV

The History of Science

Why the History of Science should be Taught

Whether or not science is taught on an historical basis, definite instruction in the history of science, outside formal experimental and theoretical lessons, should be included in every science course. The more serious work should be done in Form VI, by which time the boys will have amassed a multitude of facts, and these the history lessons will serve the purpose of placing in an appropriate setting.

If the science teacher is lucky enough to have a history colleague whose sympathies are primarily on the side of the creative genius, whether of science or art or literature or music, his task will be comparatively easy. But there are still history teachers and history books that give prominence to such stories as those of a ruffianly baronage, of court intrigues, and of military and political adventurers. The stupendous events that have really made the world what it is are almost unknown to many of our children. The names of the great pioneers and discoverers, the things they have done, of what races they were,

and how though separated by nationality each has built on the work of the rest: these are the things that history should teach. The year 1848 is mentioned in the history books as memorable for political " revolutions ": how few of them mention that that was the year when Pasteur discovered the properties of asymmetrical crystals, a discovery which led to the birth of bacteriology, and thus to modern surgery, modern medicine, and other discoveries unrolling in almost endless series? Our historical perspective has been all wrong. There are still people who would place Marlborough and Napoleon, Richelieu and Palmerston, in the same rank as such mighty creative geniuses as Newton and Shakespeare, Rembrandt and Beethoven.

But the history of science is a very big thing, too big for detailed treatment in the small amount of time available at school. The little that can be done should be supplemented by a good deal of reading. We throw out a few suggestions for lessons.

General Lessons on Earlier Science

1. *The Egyptians and Babylonians*: nations with a practical genius rather than an intellectual. Compare with ourselves.

2. *The Greeks*: Hellenic genius essentially intellectual. Thales, Pythagoras, Plato, Aristotle.

3. *Alexandria*: succeeded Athens as the centre of Greek culture. Euclid, Archimedes, Apollonius.

4. *Rome*: not intellectual; all-round excellence in things technical. Again compare with ourselves. Roman engineering and architecture. Contempt for purely scientific studies: the Romans exploited everything in the interest of immediate application.

5. *Mediæval Science*: Roger Bacon. Hostility of the Church. Why the Churches have always disliked science. The mariner's compass, printing, gunpowder: the far-reaching changes—revolutions in the true sense—that followed on these inventions.

6. *Bacon*: scientific method worked out.

7. *From Alchemy to Chemistry*: Paracelsus. Phlogiston.

8. *Ancient Astronomy*: Egyptian, Babylonian, Greek; Ptolemy.

9. *Pioneers of Modern Astronomy*: Copernicus, Tycho Brahe, Kepler, Galileo; then Newton, Sir W. Herschel, La Place.

Lessons on the History of Particular Subjects

1–6. *Chemistry*: the primitive metallurgists and their wonderful work; the early manufacture of glass, soap, dyes, pigments, medicines, oils, perfumes, and the great range of *practical* knowledge of the very early chemists; the paralysing effect of alchemy on chemistry for many centuries. The age of chemical discovery: Priestley and oxygen; Scheele and analysis; Cavendish and the atmosphere; Lavoisier and the balance and the overthrow of the phlogiston theory. Glimpses at the work of Black, Dalton, Avogadro, Davy, and perhaps of Berzelius, Liebig, Dumas, Mendeleeff, and later chemists.

So with other subjects: dwell on the big leaps forward as the result of new discoveries. Let discovery and invention, as well as pure science, play a part in the lessons; for instance:

7. *The History of Textiles*, especially as associated with the names of Hargreaves, Arkwright, Crompton, Kay, Cartwright.

8. *The History of Steam*: Watt, Fulton, Stephenson, Parsons.

9. *Iron and Steel*: Siemens, Bessemer, Carnegie.

10. *Evolution*: Darwin, Wallace, Huxley, Keith.

11. *Telegraphy*: Morse, Wheatstone, Kelvin, Marconi.

12. *Gravitation*: Newton, Einstein.

The Personalities of the Great Workers

From the multitude of the world's past and present distinguished workers, the science teacher should select a few of the very greatest, and dwell upon their lives not only as great

men of science but as great personalities. Not the least interesting side of the characters of most great men of science is their remarkable devotion to their work and their self-sacrifice. In the very forefront we should place perhaps the greatest man of science the world has yet produced, our own Newton; and then perhaps Faraday—that remarkable physicist who knew nothing of mathematics. Then perhaps Darwin. And then perhaps Pasteur. Opinions will differ about the choice of these four. That does not matter. Let the teacher choose the few (there is only time for a few) he loves best and has made his own familiar friends, and can talk about intimately. Let him make these live their lives over again, so that the boys may get to *know* them.

As for the multitude, time will not permit of much more than the association of each worker's name with his work. The name of La Place will always call up the idea of the nebular hypothesis; Koch, bacteriological investigation; Harvey, the circulation of the blood; Franklin, the identification of lightning, and electricity. The man himself we may not have time to say much about, but at least we may let his work enshrine his name.

We British people may well be proud of our share in scientific discovery. To name only a few workers: Priestley, Rumford, Black, Davy, Cavendish, Perkins, Dewar, Ramsay, Crookes, Gilbert, Boyle, Young, Davy, Faraday, Tyndall, Maxwell, Kelvin, Lodge, Rutherford, J. J. Thomson, Darwin, Wallace, Huxley, Lyell, and many a dozen more. And we have to our credit the fact that we have discovered a third of the 92 elements.

But science has no regard for national boundaries, and do not let boys tend to underrate the work of the scores of distinguished foreigners. France has given the world Cuvier and Lamarck, Gay-Lussac, Lavoisier, Dumas, Ampère, Arago, La Place, Becquerel, Moissan, and Pasteur. Germany: Guericke, Humboldt, Bunsen, Kirchhoff, Helmholtz, Virchow, Liebig, Weismann, and Koch. America: Franklin, Dana, Westinghouse, Edison, Bell, Holland, the Wrights, Tesla, and Michel-

son. Italy: Galvani, Volta, Avogadro, Marconi. Sweden: Scheele, Arrhenius, Berzelius, Linnæus, Nobel. Holland: van't Hoff, Huyghens, and Lorentz. Denmark: Oersted. Austria: Mendel. Poland: Madame Curie. Russia: Mendeleeff. Every boy should have some idea of the work that makes such names stand out so prominently, and if he has time to read up the lives of some of the workers, so much the better.

Above all, make the history alive. Let it be something more than bare bones. Take Archimedes back to his bath, and let the boys picture his glee when the overflowing water gave him the clue to finding relative densities. Picture Avogadro sitting down to solve his puzzle—how to give a rational explanation of the simple law of Gay-Lussac. Try to realize Newton's satisfaction when he discovered that the moon was merely the twin of a falling stone.

Teach the boys how to prepare helpful history charts. For instance, they might take the great names and the great events in science and chart them to a time-line, and so represent graphically the centuries of plenty and the centuries of famine.

Dates

Every boy knows the dates of Hastings and Waterloo, but why are these regarded as landmarks more worthy of inclusion in a history course than are the great discoveries of science?

Here are a few dates that every student of science should remember:

1300	Spectacles.	1836	Telegraph.
1450	Printing.	1839	Photography.
1530	Spinning-wheel.	1846	Anæsthesia.
1687	*The Principia.*	1858	Atlantic cable.
1705	Newcomen's engine.	1859	*Origin of Species.*
1764	Watt's engine.	1860	Spectroscope.
1767	Spinning-Jenny.	1868	Antiseptic surgery.
1796	Vaccination.	1876	Telephone.

These are also worth committing to memory:

Plato	.. 427–347 B.C.	Galileo	1564–1642
Aristotle	.. 384–322 B.C.	Newton	1642–1727
Archimedes	.. 287–212 B.C.	Faraday	1791–1867
Roger Bacon	.. 1214–1294 A.D.	Darwin	1809–1882
Francis Bacon	1561–1626 A.D.	Pasteur	1822–1895

The principal object of memorizing a few dates is the fixing of great landmarks. There is little point in memorizing a large number.

CHAPTER XXXV

Research: its Significance and Importance

Sixth Form boys are invariably interested in learning something about the patience and toil of those who were at last rewarded by making the discovery of what they set out to seek. The path of the research-worker is arduous indeed. Sometimes, it is true, a great discovery has been hit upon by accident, but, as a rule, scientific discovery has been the result of persistent effort, often extending over a long period. Edison's methodical world-search for a suitable material for lamp filaments is proverbial for its persistency. For a hundred years, a search for a cure for diabetes had been prosecuted, and the discovery of insulin was the eventual reward. Scores of specialists all over the world are now searching for the cause of cancer, and are making use of the work of chemists, biochemists, bacteriologists, and biologists, but so far they have not succeeded, despite their years of unremitting toil. The cause once found, a cure will probably follow.

If all the boys of our secondary schools can be convinced of the value of scientific research, they will probably spread the light, and the nation will cease to tolerate the common and

long-standing dependence of research upon chance opportunities and limited resources. Could the Government be induced to pay £10,000 a year to each of fifty of the leading consultants of Harley Street (a salary perhaps large enough to induce them to give up their present work of patching up chronic invalids), in order that they might undertake systematic research into the causes of the common ailments that afflict humanity, such ailments would probably be stamped out within a generation. But this is a most unlikely thing to happen. The practical thing to do in schools is to tell the boys what research workers have done, what they are doing, and about some of the things that still remain to be done.

Such books as Newton's *Opticks*, Faraday's *Researches*, and Darwin's *Earthworms*, should be read by all Sixth Form boys, for they show exactly how the workers set about their work and how they made their discoveries. They afford a real insight into the spirit of research, and not a few of our leading men of science acknowledge that it was books of this type that first stimulated them to research on their own account.

The boys should be told something of the work now being done by various government and university departments of research; for instance:

1. *The National Physical Laboratory*, its physical, engineering, chemical, aerodynamical, and other departments.
2. *The Government Department of Scientific and Industrial Research*: researches into chemistry, building, foods, forest products, fuel, water pollution, radio.
3. *Rothamsted Experimental Station* at Harpenden; its work on plant nutrition and diseases.
4. *The Cambridge Plant-breeding Institute*: Sir Rowland Biffin's work on wheat.

Then there are researches into insect-pest control; the Hayling Island mosquito station and Dr. Tillyard's work in New Zealand; research into fisheries; the work of the Safety-in-Mines Research Board; the scheme for Empire research; the work of research chemists in America and Germany, espe-

cially in synthetic organic chemistry and the production of drugs, dyes, perfumes, flavours, &c.; the work of the Medical Research Council; the research of individual workers, e.g. that of Mr. Baird on television. Again: there is a notable increase of international scientific relations, and something should be known about recent congresses on geology and geophysics, on genetics, and on zoology.

It is desirable to get boys interested in what scientific workers are doing all over the world, in their difficulties, their failures, their successes, their rewards. Arrange visits to places where such work is in progress. Visitors to research institutions are often given a cordial welcome.

Reports on the work of research committees and research workers should be made available. They are often too long and too technical for boys to read, but an occasional short lesson or lecture may often be given, and with profit. Consider, for instance, the last annual report of the Research Board for Safety-in-Mines. Here is a short summary suitable for a lesson:

1. Falls of ground, and types of props to be used.
2. Wire ropes for winding—corrosion of the end of the rope where it enters the capping; bending stresses in the rope where it passes over the pulley; injury of ropes by constant alteration of stress.
3. Lighting efficiency of mine lamps; electric and flame lamps.
4. Coal-dust and fire-damp explosions.
5. Mining explosives.
6. Electrical appliances for use in underground work.
7. Mine rescue apparatus.

In a mining district, a lesson of this kind would be invaluable.

When a boy leaves school, he should have been so taught and be so informed that he is able to take an intelligent interest in all scientific, technical, and industrial developments. He should be able to turn up technical reports, and obtain at least an intelligent general grasp of their contents. He should be able to discuss in a council chamber the pros and cons of proposed new applications to industrial processes. In short,

the former secondary school boy should be the disseminator of new knowledge and the intelligent adviser of the community.

Boys should also be encouraged to take an interest in subjects which are not strictly scientific but which require an intelligent garnering of facts, some of them technical, for their complete understanding. The metric system of weights and measures, decimal coinage, the advantages of linking up the natural history museum with Kew Gardens and the Zoological Gardens, and the reform of the calendar, are such subjects. They may sometimes be profitably made subjects of debate in school science societies.

CHAPTER XXXVI

The Philosophic Foundations of Science

First Notions of Philosophy

We may regard philosophy as a subject which examines critically the fundamental principles of all departments of systematic thought, including metaphysics, ethics, æsthetics, mathematics, and science. At least metaphysics will be ruled out as a possible subject for treatment in school; it requires a fuller and a more mature mind than that of a school boy. Ethics may possibly be touched upon in connexion with religious and moral training, and æsthetics in the teaching of art. In mathematics, a Sixth Form boy ought to know, amongst other things, that his school geometry is based upon a particular series of axioms adopted by Euclid; that other series of axioms, giving rise to entirely different schemes of geometry, might have been adopted, instead; and that, generally, the foundations of mathematics consist of shifting sand rather than solid rock. As regards science, the Sixth Form boy ought to be taught that the time has come for him to try to examine,

under the philosopher's microscope, the various assumptions he has been allowed to make during his scientific studies; that he must now learn to examine the nature of scientific evidence, hypotheses, induction, and laws; to examine the foundations of his mechanics, physics, chemistry, and biology. In short, he must try to learn to do as all philosophers do, viz. test the validity of the various assumptions made by science, and examine the principles of scientific method. Such work he cannot carry far: it is too difficult; but he should carry it as far as he can.

Thoughtful boys are frankly puzzled at the inability of such a famous scholar as Aristotle to follow out his own unexceptionable principles, and at his tendency to make statements in flat contradiction to what must have been easily verifiable observations. And when such boys read books on the Middle Ages, their feeling is again one of amazement that the centuries which produced such magnificent art, architecture, and imaginative literature should have been so utterly incompetent in science. The ordinary mediæval writer * seems to have used his own observations but seldom; he accepted the wildest assertions without troubling to confirm them, even when the simplest appeals to experience would have confounded them. Mediæval writers on science were content to copy what they found in the relics and pretended relics of the science of classical times; much of it reached them at third hand through Latin versions of Arabic translations from the Greek. Not only Chaucer but even Shakespeare and Milton were infected by it.

Let the boys appreciate the important fact that the mentality of any given age springs from the particular views of

* Boys may usefully read selected passages from Professor Langlois's *La Vie en France au Moyen Age*, Vol. III, dealing with the scientific writers of the age. Professor Langlois asks the question, "What scientific knowledge was at the disposal of the layman from the twelfth to the fourteenth century?" And he provides the answer by quoting extracts from eight of the best-known writers; e.g. *The Bestiary or Lapidary* of Philippe de Thaon; The *Secret des Secrets*, by Jofroi de Watreford and Servais Copala; the *Roman de Sidrac*. The false science and the absurd science in those books are amazing. The writers evidently had a passion for the sensational and the fabulous; they had a blind superstition for antiquity; and they were utterly lacking in any sort of critical power.

the world that are dominant amongst the educated sections of the community.

Not the least important thing for boys to understand is the extreme difficulty of ensuring that the facts from which they reason are objective and untainted. On this point a lesson may profitably be given on Bacon's *Idols*; and extracts from Lord Balfour's books and from Mill's *Logic*, on the same point, will repay reading. In short, the first elementary lesson in philosophy to learn is the necessity for trying to eliminate from evidence all forms of bias, in order that an objective judgment may become possible. Beliefs that are very strongly held may, of course, be mere prejudice: can we greatly blame a native of West Africa for scoffing at the statement that water may become solid? The second elementary lesson in philosophy to learn is that we are all prone to be deceived by our own senses, and to think we perceive in things qualities which do not really belong to them, qualities which are, in fact, purely the offspring of the mind. Nature is black and colourless, silent and scentless, though it is never at rest; it is our senses that confer upon it light and colour, sounds and odours, and our senses are all notoriously limited.

About the real nature of perception—how we come into cognitive contact with reality external to ourselves—even philosophy fails to tell us very much. As for physical science, it simply takes the perceptual world as it finds it, at least as far as its different precepts are mutually consistent, and concerns itself merely to discover its structure and modes of behaviour. It is enough to tell the boy that we simply do not understand the nature of perception, and that therefore it is impossible to feel absolute confidence in the foundations of science, for these *depend* on our perceptions.

Philosophy takes the concepts used by science, analyses them, and tries to determine their precise meanings and relations. It tries to replace a mere hazy general familiarity by clear and accurate knowledge. Chemistry uses the idea of *matter*, geometry that of *space*, mechanics that of *motion*. The special senses are content with a rough and ready meaning of such

terms, just as far as is necessary for their own special purpose. Philosophy probes them farther, and calls upon their users to define them accurately.—This is the real philosophy to be taught in the class-room: a persistent cross-examination concerning all terms used and concerning all premisses which are made the basis of reasoning.

Induction and Hypothesis

For science, the most important department of philosophy is probably logic, but, until within quite recent years, logicians have not helped science very much. Instead of describing the actual methods by which science has advanced, and of extracting from those methods the logical rules which might be used to regulate scientific procedure, logicians have treated discoveries as mere illustrations of preconceived ideals of such procedure. Logicians have not been familiar with the practical details of scientific problems, and science has turned to logic in vain. The logical theory of proof has little or no bearing on the scientific process of discovery.

But the modern logician has become alive to the necessity of revising his methods. He is now giving serious attention to the nature of induction, hypothesis, law, probability, and the like.

Induction is a process very much more than attaching a label to a goodly number of similar instances. The key to it is to be found, says Professor Whitehead, in " the right understanding of the immediate occasion of knowledge in its full concreteness ". The immediate occasion must be observed completely, and reasoning must be used in order to call forth a general description of its nature. " Induction is the divination of some characteristics of a particular feature from the known characteristics of a particular past." From the particular occasion, inductive reasoning proceeds to the particular community of occasions, and, from the particular community, to the relations between particular occasions within that community.

But this is not quite the whole story. It is true that physical

science is founded on observation and experiment, and that repetition implies some valid method of drawing inferences from experience, that is of induction, but no logician has ever yet succeeded in formulating a theory of valid induction that would obtain general agreement. Such continuing weakness has been described by Dr. Broad as a scandal. Until the problem of induction is solved, the foundations of science are necessarily insecure.—This is another important point to impress upon the learner, though doubtless he has long ago been warned of the danger of jumping to conclusions.

Hypothesis.—There is no more important function of the science teacher than to keep clear in his pupils' minds the nature of the difference between fact and hypothesis. An hypothesis is nothing more than a mentally constructed mechanism invented to account for an obviously close relationship amongst a group of facts. It is always highly improbable than an hypothesis will be proved to correspond to objective reality. It is much more likely to be superseded some day. All the commonly accepted hypotheses of science—the atomic, kinetic, electromagnetic, heliocentric, and evolutionary hypotheses—are all *provisional*, though they are supported by vast numbers of facts. They *may* be true, but we cannot say more. Once proved to represent objective reality, an hypothesis ceases to be an hypothesis and becomes a fact. But as long as it remains an hypothesis, it must ever be subjected to scrutiny, especially in the light of new facts.

A Sixth Form boy sometimes asks whether, in view of the hypotheses of science being nowadays so frequently superseded by others, science has ceased to represent that embodiment of certain knowledge that it was formerly considered to represent, especially during the last quarter of last century. The question is a perfectly fair one, and the teacher must deal with it.

When mediævalism began to fade away before the gathering forces of the renaissance, science began to advance rapidly, and by the beginning of the seventeenth century it went ahead in leaps and bounds. The workers of this period in-

herited a ferment of ideas attendant upon the intellectual revolt of the preceding century, and it so happened that the period provided a number of intellectual geniuses adequate to the occasion: Bacon, Harvey, Kepler, Galileo, Descartes, Pascal, Huyghens, Boyle, Newton, Locke, Leibnitz—think of them, and there was Shakespeare as well! Never before or since has the world produced a galaxy of such extraordinary talent almost at the same time.

Try to make the boys realize what great work these great men did. Contrast the world's knowledge before and after their work was done. Show how very little material they had to go upon. Show *how* they worked.

Should the Older Hypotheses be Discarded?

So much was done by them, in fact, that their successors of the next 150 or 200 years had their hands full in applying the great principles formulated, in building up a superstructure on foundations so securely laid. Newton had said the very last word, and nobody dreamt of questioning him. Physics, and even biology, eventually settled down on a mechanist basis, expressed in such concepts as absolute position in space and an elastic solid æther. But gradually new facts forced themselves on men's notice, some of them the results of experiments so refined that Newton could never have dreamt of them. Accepted physical laws had to be examined, restated, even scrapped. It became evident that science is even more changeable than theology. We can no longer subscribe to Newton's beliefs; we cannot subscribe even to our own beliefs of ten years ago. Galileo said that the earth moves and that the sun is fixed; the Inquisitors said that the earth is fixed and that the sun moves; the Newtonian astronomers, adopting an absolute theory of space, said that both move. Now we say that any one of these three statements is equally true, provided that our notions of "rest" and "motion" are fixed in the way logically required by the statement adopted.

The last twenty years have, indeed, seen the foundations

of physics torn up, and the new structure is not yet completely built. The changes have come about not only by the press of new knowledge, but also, to a great degree, as the result of a keen examination of the fundamental conceptions of physics. As Professor Whitehead writes in *Science and the Modern World*, " the progress of science has now reached a turning-point; the stable foundations of physics have been broken up; the old foundations of scientific thought are becoming unintelligible. Time, space, matter, material, æther, electricity, mechanism, organism, configuration, structure, pattern, function, all require reinterpretation. What is the sense of talking about a mechanical explanation, when you do not know what you mean by mechanics?"

But it would be a grave mistake to put things to boys as strongly as this, and to leave upon their minds the impression that our knowledge of science is entirely lacking in certitude. That Einstein has superseded Newton is true; that Newton's mechanics must be replaced by an entirely remodelled mechanics is also true. But this does not mean, and boys must not be allowed to think that it means, that Einstein is a greater genius than Newton. Einstein still looks upon Newton as his great master. Newton's laws covered all the facts available in Newton's time; his laws have to be superseded simply and solely because they do not cover certain facts more recently discovered. The actual differences in practical life are negligible, so much so that the older mechanics is likely to hold the field, as far as school work is concerned, for many a long year to come. The important lesson for the boy to learn is that, all hypotheses being provisional, it is probable that Einstein's hypothesis may itself be superseded some time. It *must* be superseded if new facts come along that cannot be brought within its ambit.

And, after all, the work of Einstein is not strictly comparable with that of Newton. The two fields of thought are different. So far as the work of Einstein is relevant to that of Newton, it is simply a greater generalization, and a broadening of the basis; it is just a case of further mathematical development. So generally: a great principle once established is

rarely discarded altogether, but it is so modified that it rests upon a basis both broader and more stable.

It was really Mach who paved the way for such positive advances as the theory of relativity and the quantum theory, and all science teachers should read Mach's *Mechanics*. A considerable portion of the book is within the scope of Sixth Form work.

Is Mathematical Reasoning Trustworthy?

There is a fundamental difference of intellectual attitude between, on the one hand, Einstein and those who, like Eddington, think with him, and, on the other hand, the more typical English physicists as represented by Sir J. J. Thomson, Sir Oliver Lodge, and Professor Larmor. The latter school demand that any hypothesis must be so constructed that it represents a mechanism which can be clearly visualized; they demand a mechanical model of the physical universe, built in normal space and time. They distrust arguments concerning physics that cannot be followed up by the mind pictorially. Einstein, and probably the greater proportion of Continental mathematicians, make no such demand. If they start off with definitely established and unassailable premisses, they are content with subsequent rigorous analysis and deduction; and if competent critics agree that this mathematical reasoning is flawless, they accept the final result as unquestionably true. And if, as in the case of relativity, the result proves to be open to possible means of experimental verification, and if this verification is carried out and supports the result arrived at mathematically, it is difficult to refute the contention that both the method and the result are as unassailable as the premisses. Still, it is probably a wholesome intellectual bias on the part of most English physicists to insist that they must always reason in such a way as if they were able to visualize the parts of the thing they are reasoning about. In any case, it is best to provide boys with means of picturing, say, the structure of the atom, or an electromagnetic wave, or what not. If boys put

their exclusive confidence in mathematical formulæ, their work may be good mathematics but it will inevitably be bad science. The reasoning will be wholly abstract, and this to immature minds is necessarily without real significance.

Most of the original prejudice against Einstein's results was due to the impossibility of visualizing a four-dimensional continuum, or of the "warping" or the curvature of space-time. But an eminent mathematician has recently said that Einstein's gravitational field-equations, like Maxwell's electromagnetic field-equations, must henceforth be regarded as the most axiomatic fundamentals of physics; and that they cannot be questioned, and never will be questioned, any more than the multiplication table will be questioned. But is not this dogmatism a little rash? New discoveries have led to the dethronement even of Newton.—Impress upon pupils the need of caution as to the final acceptance of *any* hypothesis, no matter whether the hypothesis is built upon experimental data and assumes a concrete form, or whether it emerges as an abstraction from the work of mathematicians.

As regards biological concepts, teachers should be on their guard against a too ready acceptance of the simply constructed Victorian mechanisms that seemed to explain biological phenomena so satisfactorily. Biology has yet to come to terms with psychology and to abandon the hopeless attempt to derive conscious behaviour from tropisms and conditioned reflexes, regarded as purely physical happenings. Psychology is not yet able to give biology very much help, and it therefore behoves biology to wait.

Inspire boys to muster up the courage to say, "we don't know", "we cannot understand", "the evidence is inconclusive". Tell them, and tell them again and again, that science is no longer *sure*.

Non-demonstrable "Proofs"

Should a Sixth Form course include the serious consideration of phenomena of doubtful authenticity? Take, for

instance, the question of "dowsers" and water-divining. Science has not yet been able to pronounce a verdict *ex cathedra* on the source of the mysterious force which dowsers are said to possess. Should we therefore remain agnostic and pooh-pooh its existence altogether, or should we label it fraudulent, or should we regard it as a miraculous happening? Firm faith in the hazel twig has been expressed by many eminent public men. In the recent work on the foundations of St. Paul's Cathedral, the contractors used a diviner to determine the position of water under the crypt. The Department of Public Works in Brisbane have employed a Government water-finder for at least two years. So has the Bombay Government. Directors of railway companies, and engineering, architectural, industrial, and commercial concerns are numbered among the faithful. On the other hand, science is undoubtedly divided over the question. It may be that owing to a kind of involuntary, and at present inexplicable, reflex muscular action, the movement of the hazel twig held in the hands does enable some few sensitives to detect subterranean supplies of running water in places where there are no surface indications of its presence. This is not a place to pronounce an opinion, for or against, on the question of water-divining, but the lesson for the boy to learn is that, whenever claims for the existence of a new phenomenon are put forward, it is the business of science to investigate it; and that science must be extremely cautious in basing conclusions on negative results. Science is stultifying itself if it pronounces judgment before considering ascertained and ascertainable facts, if such facts there are. Science has rightly condemned such charlatans as phrenologists, physiognomists, astrologers, and the like, but it has no right to condemn until it has investigated.

Then there is the question of psychical research. School boys are constantly asking questions about it, and embarrassing questions, too; and science masters must be prepared with reasoned answers that will give at least some measure of satisfaction.

Psychical research must, of course, be clearly distinguished

from spiritism.* Psychical research purports to be the study of supernormal phenomena, and not only such physical phenomena as telekinesis, the production of sounds and of psychic lights, and the formation of ectoplasm, but also such mental phenomena as clairvoyance and telepathy. Lodge and Richet are admittedly psychic researchers of the front rank, but, with precisely the same facts to go upon, the two have come to diametrically opposite conclusions. Lodge has come down definitely on the side of spiritism, being convinced that survival is proved by a rational interpretation of the facts. Richet interprets the facts from an entirely different standpoint, and is irrevocably opposed to the spiritistic hypothesis. Indeed he holds that the hypothesis is actually disproved by some of the very facts of psychical research.

The lesson for the boy to learn is the necessity for being extremely cautious in coming to conclusions about things concerning which recognized authorities disagree fundamentally. The boy may also rightly be taught to have scant respect for a man who " has never in his life been to a séance and never intends to go to one ", and yet treats with contumely those who are earnestly trying to get at the actual facts. The opinion of any man, however great, or of any body of men, however influential, on a subject which they deliberately refuse to investigate, either because it does not interest them or because of a preconceived idea that the phenomena involved are fraudulent, is necessarily worthless, and this every boy should clearly understand. It is a sad commentary on human nature that those men of science who take up the study of psychical research, even in these days of generous tolerance, run the risk of losing caste and even of suffering persecution from their old colleagues. Science workers who denounce the persecutions of the Middle Ages stultify themselves when they calmly take the very chair from which they drove the mediæval church. Psychical phenomena *may* be of a wholly fraudulent character: the only concern of science is to undertake an unprejudiced investigation, and then, but not till then, to pronounce judgment; and that

* " Spiritualism " in this sense is, of course, an absurd term.

judgment, to be scientific, must be cold and uncoloured. Tell the boy frankly that there are aspects of human personality about which science fails to give a satisfactory explanation; that the richness of reality seems to be as inexhaustible in the unplumbed depths of personality as in the manifestations of the external world.

The science teacher is sometimes asked by his boys to expound different points of theology, more especially points arising from the interpretation of the biblical narrative. It is unwise to burke such questions, and it is a good plan for science teachers and the teachers of religious instruction occasionally to compare notes. A generation or two ago it was the fashion in certain science circles to be aggressively rationalist and dogmatic. Gradually the attitude gave way to a milder agnosticism which, in its turn, is being replaced by a general admission that the little knowledge we possess is as nothing compared with our still profound ignorance both of nature and of ourselves.

Both science teachers and teachers of religious instruction will probably agree that pupils may properly be told, on the one hand, that credulity is no longer looked upon as a virtue, doubt no longer condemned as a sin; on the other hand, that in biblical and liturgical literature there are many crudely expressed thoughts, but that, in spite of this crudity of expression, the thoughts themselves may enshrine profound truths that very few people are really competent to plumb. Some crudity of expression is almost inevitable whenever an attempt is made to clothe in words for popular understanding some particular idea, whether the idea belongs to science, or to philosophy, or to theology.

The biological theory of the evolutionary origin of man seems now to prevail generally among educated members of the English churches, clerical as well as lay, but no systematic attempt is being visibly made to modify the traditional dogmatic system, in view of the new knowledge which so profoundly affects it. Yet the pressing need of such theological restatement can escape no reflective person. It is, however,

certain that the new doctrinal view is best disseminated with extreme caution and reserve, and that any authoritative far-reaching restatement of theological dogma would at present be dangerous. Progress is indispensable, but caution is indispensable too. And in the Sixth Form this is the best note to strike.

The boys should know that the attitude of men of science towards their theories has undergone a profound change in the last twenty or thirty years. There is now a much greater caution. The hostility of laymen towards science is therefore tending rapidly to diminish, though there are still a few whose natural cast of mind is alien to the garnering and classifying of undisputed facts, and who, instead, repose confidence in intuitional modes of apprehension. Men of science are now the first to admit that the object of their theories is not to reveal the real nature of things, but to co-ordinate the physical laws revealed by experience. Philosophy goes farther, beginning where science leaves off.

An Outline Lesson on Inference

Here is an extract from *Scientific Method*, typifying in outline the kind of lesson contemplated in this chapter.

" Inference " is a very ambiguous word. " When we *infer* one fact from another or others, we believe that fact ' by reason of ' our belief in those others; and when we *prove* one fact by means of another, exactly the same expression is commonly used. In both cases there is ' reasoning ', and, accordingly, both that from which the inference is drawn and that on which the proof is based, are indiscriminately called, in popular language, the *reason*. We reason when we proceed from premisses to conclusion, arriving at new truths by means of old ones; and we reason when, having already an assertion before us, we produce arguments to support it, even if such arguments be then for the first time thought of. Again, the term ' premisses ' is sometimes used for the *grounds of proof*, and sometimes for the *data of inference*; ' conclusion ' sometimes means that which is *discovered* and sometimes that which is *proved*."

Inferences are of very varying degree. They may be merely our first vague guesses; they may be the final and certain results of the most careful inquiry.

It would be convenient to restrict the term Inference to the process of reaching a belief, and to speak of a Conclusion following from its " premisses " or " data "; and to regard Proof as the process of establishing a belief on a firm foundation after it is already somehow reached. Thus, in the case of proof we should speak of an assertion " guaranteed by " its " reasons ", or " resting upon " its " grounds ". The problem of Proof is thus narrower and more definite than that of Inference. Instead of asking at large, " *What* conclusion may be drawn?" Proof asks, " Is such and such a reason warranted?"

It is evidently immaterial to an argument whether the conclusion is placed first or last. But a premiss placed *after* its conclusion is usually called the *reason* of it, and is introduced by a causal conjunction (*since*, *because*, &c.). The illative adverbs (*therefore*, &c.) designate the conclusion.

Perplexity often arises from the fact that these conjunctions and adverbs have also another signification, being employed to denote, respectively, *cause* and *effect*, as well as *premisses* and *conclusion*. For example:

(1) The soil is rich *because* the trees on it are flourishing;
or (2) The trees are flourishing and *therefore* the soil must be rich.

In both examples the italicized words denote the connexion between *premisses* and *conclusion*; for clearly the luxuriance of the trees is not the cause of the soil's fertility but only the cause of *my knowing* it. But if I say:

(1) The trees flourish *because* the soil is rich;
or (2) The soil is rich and *therefore* the trees flourish;

I use the same words to denote the connexion of *cause* and *effect*, for in this case the luxuriance of the trees, being evident to the eye, would hardly need to be *proved*, but might need to be accounted for.

In some cases the cause is employed to *prove* the existence of the effect. For instance, when from favourable weather

anyone argues that the crops are likely to be abundant, the *cause* and the *reason* coincide. And this contributes to their often being confounded together in other cases.

CHAPTER XXXVII

Science and Humanism

It is an important part of the work of the science teacher to leave on the mind of the boy the definite impression that, despite appearances, there is no natural antagonism between science on the one hand and humanism on the other.

It was Mr. John Galsworthy who said: " We have made by our science a monster that will devour us, unless by exchanging international thought we can create a general opinion against the new powers of destruction so strong and so unanimous that no nation will care to face the force which underlies it." It is, indeed, a common thing for people to look upon science as a disturbing influence in human affairs, and to sigh for the simple life—away from the restless spirit of inquiry into all things visible and invisible in the universe. During the last fifty years there have, of course, been more scientific discoveries and applications than in the whole previous history of the human race; and we may be on the threshold of developments by which forces will be unloosed and powers acquired beyond those hitherto known. Whether these should be used to promote social well-being and international amity is not a question for science but for the public and its leaders. When at the Guildhall Mr. Baldwin urged that more pains should be taken to apply the methods of science to human problems, it was obvious that he meant, not the development of poison gases and high explosives, but the principle of facing facts honestly and fearlessly, and of basing just conclusions on them. If sound principles of progress are to be determined, the methods applied to social problems must be the methods of science.

Sixth Form pupils should be taught that modern civilization

is really built on science, and that almost all industrial developments had their origin in principles established by investigators who were working purely for the advancement of natural knowledge. Faraday's discovery of the principle that a moving magnet may create a current of electricity in a coil of wire near it led to the construction of the dynamo and to the birth of the great industry of electrical engineering. All the pure copper required for electrical purposes is produced by electrolysis; so with aluminium; and the principles of this process were discovered during scientific investigation by Davy and Faraday. Examples of discoveries and their subsequent applications may be cited in almost any number: Moissan, the electric furnace, and the enormous production of steel; the discovery of X-rays and their employment in surgery and other arts; the manufacture of liquid air, and modern refrigerating machines; the metal tungsten and the manufacture of high-speed tool-steels; chromium and stainless steel; thorium and cerium and gas-mantles; argon and gas-filled electric lamps; neon and the pink glow-lamps of illuminated advertisements; helium and the inflation of dirigibles; and so on indefinitely. Let the boy understand that before things can be made in this way they must be *discovered*, and that it is the particular function of science to reveal them. Every new scientific discovery, however remote at the moment it may seem from the ordinary practical needs of life, may be seed destined to produce a mighty tree. The scientific investigator discovers, the engineer or inventor recognizes and applies the discovery, the manufacturer makes it commercially profitable; and it is the business of the community to see that it is used to promote social welfare. Progress is inevitable, and whether this is accompanied by increased happiness or not depends on ourselves.

But the history of science is by no means a record of steady progress. It was born amongst the Greeks who made great advances in mathematics, astronomy, and medicine, but their backwardness in invention was due to their adoption of a doubtful standard of values. It was the Greeks who taught themselves to think that it was a finer thing to be an orator

than to be a scientific investigator. The Romans were no very great admirers either of originality or of intellectual progress, and after the time of Galen there is a barren scientific waste of more than 1000 years. During the Dark Ages, with their long orgy of superstition, massacre, and pillage, the general barbarization of the world was inevitable, a result which neither Hellenistic philosophy nor Catholic Christianity did much to check.

The materialistic trend of science in the nineteenth century was the consequence of its rather one-sided development. Biology advanced far more quickly than psychology, and physics and chemistry in their turn were ahead of biology. But the tendency to reduce life to mechanism is now being abandoned in response to protests from science itself, and the problems of conscious life are now seen to involve such profoundly difficult questions of a metaphysical character as to seem insoluble. The former arrogant claims of science to infallibility have passed away, though there are still with us a few sturdy representatives of the old school almost as intolerant as were the Spanish inquisitors.

School boys should be taught to exercise caution in thinking that science is likely to bring in the millenium. Can it, in fact, be maintained that motor-cars and wireless telegraphy and telephony, synthetic dyes and ferro-concrete skyscrapers, are making men better or happier? By saving the unfit, is medical skill raising the standard of the race? If tanks and poison-gas, air-raids and submarine sinkings, be weighed against field sanitation and plastic surgery, did science make the last war less terrible or more terrible? We now know that civilizations long since extinct attained remarkable levels of progress; are we not then justified in feeling doubt about the fate of the present order of things? Can science save us? The fact is that science has provided the tools of material progress but has not directed their use. Apparently there is no country in the world where the opinion of science is decisive in any matter affecting the welfare of the people; and the last word whether science is to be used to advance or to check the interests and the happiness of the community rests with the politicians.

Compared with the training of a business man, a training in science is almost a handicap. A successful business man, or, even more so, a politician, owes his success almost entirely to his powers of divining the wishes and thoughts of his fellow-men. But a man of science spends his time in dealing with an inanimate world which cannot be influenced by tact, persuasive powers, or individuality. In fact, the inexactitudes and tactful misrepresentations so characteristic of the business and political world are exceedingly distasteful to a man trained in the clear honesty and rigour of scientific thought; and when he is engaged in delicate negotiations of any sort, he is at a positive disadvantage compared with his commercial fellow-men, and is apt to be overmatched if not overreached. The trained man of science is likely to be much less tactful and much less persuasive, and will probably be a worse judge of character than a man who has spent an equally strenuous number of years either in persuading people to buy something they do not really need, or in making the worse appear the better reason.

Then is a man of science merely an intellectual machine, perfectly honest though rather stupid in his human relations? Has he no claim to culture?

Inasmuch as science has changed the whole background of our thought by giving us a new knowledge of man's origin and place in the universe; inasmuch as every branch of human thought feels the influence of this new knowledge; inasmuch as science has made the outlook of our grandparents and the very postulates of their thinking incredibly remote: assuredly science has a claim for a prominent place in the sun.

We may ungrudgingly admit that, as an instrument of education, science cannot replace what are traditionally called the humane studies. But knowledge of scientific truth and appreciation of scientific method are the very foundations of modern humanism, and, without them, human thought would progressively degenerate. Science has practically freed the civilized world from the thraldom of base superstition; and it has banished irrational fear.

Inasmuch as our national shortcomings are mainly of an intellectual character, it is as much the business of the science teacher as the teacher of any other subject to make boys conscious of them. A boy very naturally, perhaps quite rightly, takes pride in race, but of course his pride is steeped in prejudice. Grant him our readily recognized national merits—our sense of right and wrong, our justice, our tolerance, our enterprise, our moderation. But on the other side?—our distrust of ideas, our tendency to belittle the trained and disciplined reason, our incurable sentimentality. Sting the boys into a full realization of the fact that we are the intellectual inferiors of many of our Continental neighbours. Shame them into the sense of the further fact that as a nation we are too lazy to think. Remind them that, for instance, all Asia is at last intellectually awake, and that therefore it behoves them to learn to think, to think hard, to think of the future.

Impress upon them that the judgments of science are usually judgments of facts and not judgments of human values, and that therefore their special work in science requires supplementing by a careful study of humanism; in short, that they must read widely from the great masterpieces of literature. The data of human values cannot be isolated and analysed as the data of science can be isolated and analysed. Human values are inseparable from time and change. If we are ever to understand the causes of the clashings of men's motives, we must get outside the laboratory, and study men. Not infrequently students of science fail to realize that the importance of such a study is supreme.

> "Trace science then, with modesty thy guide:
> First strip off all her equipage of pride;
> Deduct what is but vanity, or dress,
> Or learning's luxury, or idleness;
> Or tricks to show the stretch of human brain,
> Mere curious pleasure, or ingenious pain;
> Expunge the whole, or lop the excrescent parts
> Of all our vices have created arts;
> *Then see how little the remaining sum.*"

PART IV

ACCOMMODATION AND EQUIPMENT

These suggestions may help science teachers who are responsible for giving advice on the fitting up of laboratories and on the provision of equipment.

It must be borne in mind that even after laboratories have been built and initially equipped, a considerable annual expenditure on upkeep is necessary. If books for the science library are to be included, the total annual expenditure on science equipment is likely to be in the neighbourhood of nine or ten shillings *per every pupil in the school.* School authorities naturally raise objections to spending more than about £20 on any single piece of apparatus, and it is a good thing to make an appeal, every three, four, or five years, to the friends of the school for subscriptions to cover the cost of the few desirable items likely to be listed at £30 or £40 or more. The necessary instruments for a school observatory will almost certainly have to be obtained in this way.

CHAPTER XXXVIII

Laboratories and Equipment

Laboratory Accommodation Generally

Science masters who have the advantage of collaborating with the school architect when a new science block is projected will have themselves to blame for any imperfection that may show itself later. There are now about the country so many well built, fitted, and equipped laboratories that there is no longer any excuse for providing new laboratories which will not turn out to be a success in the working. The Board of Education, or the Science Masters' Association and the Association of Women Science Teachers, will doubtless always be willing to give the names of schools where approved laboratories may be inspected, and a science teacher who goes on such a pilgrimage will be able to advise the school architect over the hundred and one details which are so important from the teaching point of view. Beware of accepting stock designs from the manufacturers.

Certain main principles will occur at once to every science teacher. In order that vibration may be reduced to a minimum, all physical laboratories should be placed in the basement, or at least not higher up than the ground floor. To ensure the efficient ventilation of the whole science block, chemical laboratories should be placed on the top floor, though it has to be remembered that this will entail additional cost in the plumbing, a fact which may make the school authorities grumble. Efficient ventilation is, however, essential. So is adequate lighting: and the windows should be so placed that they face neither the teacher nor the pupils. Drainage, sink accommodation, water supply, gas, and electric current, may never prove quite satisfactory unless details are carefully thought out beforehand. The drainage is particularly liable

to give trouble, especially in chemical laboratories where there are necessarily numerous taps and sinks. Let the waste, from each bench-sink, drain through a vertical pipe into an open half-channel (or a V-shaped channel) having a slight fall, running the whole length of the bench, and emptying into a large trap at the bench end, this trap again emptying into a half channel under the floor, leading to the wall exit. Arrange for the half channels to be easily opened for inspection and for cleaning. The only closed pipes in the laboratories should be the short straight pieces from the sinks. Remember that rubbish *will* go down the sinks, and that therefore stoppages are inevitable if closed pipes are used.

Let each main laboratory be large enough for a whole class of thirty. It is wholly unnecessary for classes always to be divided for practical work. If there is an intelligent laboratory assistant available (as there ought to be), who can go round and guide the pupils in their manipulative difficulties, a science teacher ought to be able to cope with a class of 28 or 30 pupils, in any elementary lesson.

In laboratories with double benches, where the pupils are back to back, the gangways should be 4 feet wide. If the benches are single, a 3-foot gangway is wide enough.

Central benches are always advisable for main work, but side benches for special types of work are useful in laboratories of all kinds.

Laboratories should be so planned that the total area of the room divided by the number of pupils to be accommodated is 30 square feet. Thus for 30 pupils a laboratory 36 feet by 25 feet is necessary. This allows room for a small demonstration table for the teacher. Short demonstrations in the laboratory are, of course, often necessary, but longer full-period demonstrations are best given in the lecture-room.

A small school of 150 pupils will have to manage with one laboratory for all purposes. When the number approaches 200, a second laboratory is indispensable, and then separate physical and chemical laboratories become possible. If, in a school of 200, biology has to be taught, the physical or the

chemical laboratory must be used, according to the kind of work to be done; for experiments requiring the use of much water, the chemical and not the physical laboratory should be used. In large schools where elementary and advanced physical laboratories, elementary and advanced chemical laboratories, and a separate biological laboratory, are provided, the science work can naturally be organized much more effectively.

Lecture-rooms

All large schools should have at least one good-sized lecture-room, containing a teacher's demonstration table, with gas, current, water, and sink, and with ample drawer and cupboard accommodation. A spacious and properly ventilated fume-chamber within the wall between the lecture-room and preparation-room, and either a prepared white wall-surface behind and above the blackboard or a roll-up white linen sheet, for lantern purposes, should also be provided. The lantern should be a fixture at the back of the room, but it is useful to have a second and smaller lantern at the left end of the bench, and a small screen on the wall to the right of the bench, available for the teacher's occasional use during the course of an ordinary lesson. The demonstration table should be on a *low* platform; otherwise the pupils in the front row may not see what is going on. If rising tiers of seats are used, 4-inch risers are amply sufficient. There is no point at all in having the back rows of pupils high above the ordinary floor-level, breathing the vitiated atmosphere in the upper part of the room.

A lecture-room should provide 14 square feet of floor space per pupil. But if the room is designed for combined classes, 12 square feet per pupil is sufficient. In those schools where a lecture-room cannot be provided, a demonstration table should be placed in one of the class-rooms.

For all the commoner demonstration-table experiments, a separate outfit of apparatus should always be ready for use, kept in allotted places in the preparation-room.

Preparation-rooms, Balance-rooms, &c.

A preparation-room communicating with the lecture-room by means of a large-sized fume-chamber in the intervening wall is very useful. The laboratory assistant should keep the sashes and sash-cords, on both sides of this cupboard, in good working order, and he should see that the ventilating gas-jet is alight before a lesson begins. The cupboard, drawer, and shelf accommodation of both the preparation- and the store-rooms should be carefully planned out, and waste of space thus avoided.

Opinion has now definitely crystallized against the use of a separate balance-room for elementary work. A slate-slab, or a rigid bench, fixed against one of the long walls of the elementary chemical laboratory is now preferred, balance cases being, of course, provided. The supervision of a separate balance-room is not always possible, crowding is inevitable, and discipline is seldom what it should be. But the few fine balances used by the Sixth Form should always have a special home of their own, and a small well-lighted room should be given up to them.

It is a good plan to provide all Middle Form boys with boxes of fractional (German silver or aluminium) weights for their exclusive use for the term. At the end of the term the boxes should be delivered up, all lost weights paid for, and replenished from stock for the next term.

If the subject of light is to be taken up seriously, a separate dark room is indispensable. Means should also be provided for darkening both the physical laboratories and the lecture-room. Black blinds fixed at the *bottom* of the windows are to be preferred.

Chemical Laboratories

For elementary chemistry, single benches are the best, and they should be quite free from shelves. The few necessary bottles of reagents may be kept on a slab of glass let into the

back of the bench, with a 2-inch-high ledge behind, to prevent the bottles from being swept off by passers-by. Remember the tendency of the stoppers of the bottles of sodium and ammonium hydroxide and sodium carbonate to become fast; rubber stoppers are better than glass; if glass, then cover with paraffin.

The sinks in the benches should be large enough for use (with bee-hives) as pneumatic troughs, and should therefore be provided with Doulton's perforated plugs. Separate pneumatic troughs are expensive, unnecessary, take up much bench-space, and tend to make the benches very wet and messy. The water-taps should be high enough to allow the placing of large beakers under them, but not so high that splashing may become a nuisance.

Let the bench-tops overhang the drawers and cupboards underneath, sufficiently for pupils to sit in comfort. Let there be space underneath the cupboards for the toes, again for the purpose of comfort (but see that this shallow dark space is periodically cleaned). Arrange the bunsen connexions so that the taps cannot be accidentally turned by people passing them. Provide recesses for stools; also for rubbish bins, and see that the bins are cleared and cleaned periodically. And so on, and so on.

Each pupil should have 3 feet 6 inches of running length of bench, and 2 feet of width; a bunsen connexion to himself, and a sink which he shares with one other boy. Let each cupboard and each drawer at every working place be divided up in such a way that each space contains its specified article and nothing else. An open cupboard or drawer should show at a glance if everything is there and in its proper place. All broken and worn-out articles should be shown to the teacher or to the laboratory assistant, replaced, and a record made. A small fine should follow a careless breakage, the fines being handed over to the science library. Let every pupil have a list of his apparatus posted up in his cupboard, and let everything be inspected and checked every term.

A combustion hood may with advantage run the whole length of one end of the chemical laboratory, and all experi-

ments in which noxious fumes are given off should be worked under it. See that it is efficiently ventilated. Let the Kipp cupboards be large rather than small; see that the sashes run easily; let the flames feeding the ventilation shafts come from a burner placed vertically, not horizontally: laboratory fires have been rather frequent because of neglect of some kind of safety-flame arrangement.

Side-shelf accommodation for special reagents should be ample; so should cupboard accommodation for chemicals. Let one small cupboard be provided with a Chubb's lock, to contain the costly and dangerous items. Even phosphorus and sodium are best kept locked away. (Law suits, consequent upon laboratory accidents, are by no means unknown.) Let all reagents be properly labelled and be arranged in a fixed order, perhaps alphabetically.

A special cupboard of the cabinet type, divided into compartments for cork-borers, corks, files, pliers, &c., for general purposes is useful.

Steam-baths, a still, &c., will, of course, be provided in all chemical laboratories.

The laboratory assistant (not the boys) should be responsible for keeping all reagent bottles stocked. He should mark each label with the degree of concentration of the solution in the bottle. He should paint with paraffin, *neatly*, all newly stuck on labels. He and the bottle-washer should be responsible for keeping the laboratory in good order and scrupulously clean, also for reporting carelessness of individual pupils. *An ill-organized and untidy laboratory tells a visitor at once that the responsible teacher is inefficient*, for the ultimate responsibility is certainly his.

An advanced chemical laboratory will, as a rule, be smaller, and provision will be made for the much larger number of reagents now required. Double benches four feet wide, with central sinks, will be the normal arrangement. A small off-room for the few necessary fine balances is also desirable. Sixth Form boys ought to be made personally responsible for much of the routine work of their own laboratory. They should,

for instance, make up their own solutions for volumetric work, as part of their ordinary training.

Reference has already been made to the provision necessary in case of accidents, with instructions as to procedure. It is also a good thing to frame and place in a conspicuous position a few laboratory rules, to be gone over once a term in all Middle Forms.—When heating a test-tube or boiling-tube, incline it away from self and neighbours; never let the flame touch that part of the tube above the contained liquid; round the sharp edge of a glass tube before pushing through a cork; never handle sodium or phosphorus with the fingers; never lay down the stopper of a reagent bottle; and so on.

Physical Laboratories

Ample bench space is essential for experiments in physics. The working benches should be of the nature of plain strongly framed, rigid tables, about 2 feet 9 inches high, centrally placed, with tops of hard well-seasoned wood, unpolished. The double table should be 3 feet 6 inches or 4 feet wide, with a running length of 3 feet 6 inches for each boy; and there should be a four-way bunsen connexion for every four boys. The 7 feet of running length is certainly desirable for every two boys doing advanced work: in electrical experiments it sometimes happens that several large pieces of apparatus have to be connected together. Sinks in the benches are undesirable, but there should be at least two large sinks in opposite corners of the room, with water-supply and waste, and long draining-boards. Low-voltage current, converted from the main, should be available for the pupils' use. (There is a very useful article in the *School Science Review* for June, 1925, by Mr. G. W. Baker, giving full details of the "Rectification of Alternating Currents" for school laboratories.) Adequate side-bench accommodation is also desirable, especially for the best galvanometers and other instruments the accuracy of which may be impaired if they are frequently moved about.

Heat experiments in which much steam or vapours are given

off should be performed in the elementary chemical laboratory. Any risk of injury to physical apparatus should be foreseen and guarded against.

Cupboards for storage must be large, in view of the large size of much of the apparatus. In the elementary physical laboratory, apparatus should, as a rule, be sufficient for a whole class to be working the same experiment at the same time, two boys being told off to use the same set of apparatus. In an advanced physical laboratory, the work is necessarily organized differently, the requisite apparatus being too expensive for many sets to be purchased.

Unless there is a separate mechanics or engineering laboratory, overhead rails in the elementary physical laboratory should be provided, fitted with clamps, &c., for suspension and pendulum experiments. But in all large schools for boys, a separate mechanics laboratory is advisable. Then mechanics will receive the attention it demands, and there will be room for working models and other special apparatus.

A mercury bench is a useful adjunct to any physical laboratory. So is a soldering bench.

If the school is provided with workshops, breakages and the making of simpler forms of mechanical and physical apparatus may be entrusted to the responsible instructors. If not, one end of the elementary physical laboratory (unless a separate room can be provided) should be fitted up with a carpenter's bench, a smith's vice, and a bench for soldering, brazing, and glass-blowing.

If often happens that the same lecture-room is used for demonstrations in both chemistry and physics, and there is sometimes a clash of opinion whether the charts on the walls should be representative of chemical or of physical processes. It is doubtful wisdom to put charts of any kind on the walls. They are rarely or never looked at attentively. It is better to bring them out when they are to be discussed. It is preferable to decorate the wall space with portraits of the world's great science workers, past and present (*Nature* publishes a large number of them).

Biological Laboratories

Few schools have more than one biological laboratory, and commonly that is used mainly for botany.

The first essential of a botany laboratory is good light. The room should have an aspect that will ensure plenty of sunlight for growing plants. The main benches should be central and consist of strongly made tables with tops of well-seasoned wood, unpolished. A side bench 2 feet wide should run the whole length of one side of the room, under the windows; it is useful for physiological experiments, for other experiments that require a specially good light, and for work with the microscope. At least two large sinks, with water and waste and good draining-boards, should be provided at opposite corners of the room. A demonstration table, with sink, water, gas, drawer, and cupboard accommodation is also necessary. A glass-house as an annexe should be looked upon as an almost indispensable part of a botany laboratory. Failing that, a Wardian case (a glass case with an automatic heat regulator) should be provided; also special provision for germinating seeds. Ample provision of cupboards and shelves is necessary, and a special side bench 4 or 5 feet long with shelves above for reagents is very useful. A narrow shelf above the long side bench under the windows is useful for pot plants, &c. And of course a school garden is as necessary as a laboratory.

The same room will, as a rule, be used for other biological subjects (zoology, physiology, &c.).

The School Observatory

School authorities generally look upon an observatory as a luxury and are disinclined to provide it. If an appeal to some generous friend of the school can be made successfully, and the cost of the necessary instruments thus met, the school authorities may perhaps be induced to find the money for a small domed building. The principal instruments are an equatorial (say a 4½-inch), an altazimuth, and a transit instru-

ment (say a $3\frac{1}{2}$-inch), though the first two are easily combined into one. Everything depends on the amount of money available.

Apparatus and Equipment

Before making purchases, make out a list of experiments to be performed, and of principles to be experimentally demonstrated. Then differentiate between the experimental work to be done by the teacher himself, and that to be done by the pupils; and purchase supplies accordingly.

In addition to the usual stock of apparatus for all kinds of elementary work, and the flasks, beakers, tubing, chemicals, reagents, &c., for everyday use, the following are some of the articles to be looked for in a well-equipped school.

MECHANICS AND HYDROSTATICS (do not buy useless toys: the real things cost very little more):—

Fletcher's trolley (several).
Atwood's machine (hardly necessary these days).
Hick's ballistic balance.
Kater pendulum.
Young's modulus apparatus (for tension and for bending).
Shear modulus apparatus.
Machines, including substantial pulley blocks.
Screw-jack.
Crane.
Roof-truss.
Gyroscope.
S. H. Motion apparatus.
Moment of inertia apparatus.
Geryk air-pump.
Mercury pump.
Barometer, on Fortin principle (about £10. A Fortin itself is too dear and is quite unnecessary for school work).
Aneroid, with working parts visible.
Bramah press.
Model pumps in glass (use very gently).
Boyle's Law (one standard apparatus for demonstrations, two or three of a simple form).
Hare's apparatus (several: let tubes be varied as to bores, inclination, &c.).

Working wooden models of link-motions and other parts of a steam-engine are useful.

SOUND:—

Wave-motion apparatus.
Savart's toothed wheel (ratios 4, 5, 6, 8), and whirling table.
Siren.
Range of tuning forks.
Electrically driven forks.
Sonometers.
Tyndal's resonator and bell.
Resonance apparatus.
Organ-pipes (various).
Koenig's manometric flames apparatus.
Kundt's tube.
Sensitive flame apparatus.
Chladni's plates.

OPTICS:—

Common photometers.
Electric photometer.
Mirrors, various, including a kaleidoscope.
Optically worked prisms.
Fresnel's prism.
Optical bench, accurate.
Optical benches, rough.
Lenses, a good stock, including achromatic combinations.
Spectroscope.
Spectrometer.
Interference apparatus.
Diffraction apparatus.
Diffraction gratings.
Newton's rings.
Polarizing set.
Optical lantern (a good type).
Sextant.
Caustics mirror.
Telescope.
Microscope, common (an eye-piece and an objective, to take to pieces).
Microscope, good quality, for magnification measurement.

HEAT:—

Coefficient of linear expansion of metals apparatus.

Dulong and Petit's apparatus for coefficient of absolute expansion of mercury.

Coefficient of air expansion (constant pressure, constant volume).

Vapour pressure apparatus, various types, including Regnault's.

Latent heat of steam apparatus.

Gas liquefaction apparatus.

Vapour density apparatus (Hoffmann's, Dumas's, Victor Meyer's).

Boys's radio-micrometer (expensive: secure as a present; so with other very expensive items).

Nobili's thermopyle.

Langley's bolometer.

Joly's, Bunsen's, and other common calorimeters.

Clement and Desorme's specific heat of gases apparatus.

Simmance-Abady gas calorimeter (expensive).

Lewis Thompson's calorimeter (for evap. point of coal).

Berthelot-Mather's calorimeter, with bomb (for calorific value of fuel) (expensive, because of high cost of platinum).

Callendar's mechanical equivalent of heat apparatus.

Pyroheliometer (expensive).

Accurate thermometers.

Sectional working models of steam-engine. (See under mechanics.)

ELECTRICITY AND MAGNETISM:—

Magnetometers (various).

Vibration boxes.

Dip-needle (about £3, 10*s*.).

Clinometer.

Prismatic compass.

Primary cells in variety; accumulators.

Standard cells: Weston normal, Daniell's, Fleming's. (Write to the National Physical Laboratory for instructions for setting up standard cells of the Weston type.)

Voltameters, various.

Joule's calorimeter.

Kohlrauch's apparatus for conductivity of electrolytic solutions.

Galvanoscopes, sensitive and rough.

Galvanometers, in large variety (common reflecting, sensitive dead-beat; sensitive ballistic; unipivot types; Ayrton-Mather's reflecting, with interchangeable ballistic and dead-beat coils).

Ammeters and voltmeters, accurate and commercial (of good range).

Milliammeters and millivoltmeters.
Combined ammeter and voltmeter, magnetic control.
Combined ammeter and voltmeter, gravity control.
Potentiometers (dial and other patterns).
Bridges, various (one with potentiometer).
Resistance boxes and frames; lamp resistances.
Post Office boxes.
Standard resistances.
Rheostat; megohm; carbon resistance.
Condensers, standard and common.
Thermocouples; Nobili's thermopile; electrical pyrometer.
Langley's bolometer.
Induction coils, various. (A 6-in. spark coil for X-ray work, &c., will cost over £20.)
Geissler's, Crooke's, and Röntgen's tubes.
Fluorescent screens.
Dynamo and motor (small models will do, if a generating station can be visited).
Thermionic valves.
Wireless sets—stock parts for making up.
Quadrant electrometers, Torsion balance, Wimshurst machine } now almost a luxury.

CHEMISTRY:—

Balances and weights, common; the usual stock for Middle Forms.
Sets of German silver (or aluminium) fractional weights, 3*s.* a set, in box with forceps, one set for each boy.
Two or more fine balances for Sixth Form boys, to turn from 200 gm. to $\frac{1}{10}$ mgm.
Two or more boxes of weights, 100 gm. to 1 mgm., and 50 gm. to 1 mgm., gilt or platinum plated.
Still and condenser; or
Battery of drying ovens and still combined.
Vacuum still.
Water baths.
Filter pumps: Bunsen's, Korting's with vacuum gauge, common forms in variety.
Fractional distillation tubes.
Furnaces: crucible, muffle, combustion.
Gas analysis apparatus: Stead's, Orsat Pryce's.
Gas burettes and absorption pipettes.
Apparatus for composition of HCl, NH_3, NO, CO_2, &c.
Beckmann's depression of freezing-point apparatus.

Beckmann's elevation of boiling-point apparatus.

Nitrometers.

Steel cylinders of gases: O, CO_2, SO_2.

Standard flasks and graduated vessels (including a small number of standard burettes and pipettes verified and stamped at the Nat. Phys. Lab.).

Platinum crucibles, foil, wire. (Present cost is very high; hence, as far as possible, substitute vitreosil.)

Vitreosil apparatus: basins, crucibles, combustion boats, beakers, combustion tubing, watch glasses, reduction tubes; all acid-proof and heat-proof.

$\frac{1}{10}$ degree thermometers, 1 or 2.

One Beckmann thermometer, reading to $\frac{1}{100}°$.

Organic material including a plentiful supply of alcohol (a rebate of duty is obtainable).

Useful: hot-water funnel for hot filtrations; double-slotted anti-parallax cards for slipping over burettes; draining-rack with pegs for test-tubes, &c.

BOTANY:—

Microscopes with $\frac{1}{2}$-in. and $\frac{1}{6}$-in. objective (Abbé condenser, polarizer, and mechanical stage unnecessary for all ordinary work).

Microscopes, one or two of better quality (one $\frac{1}{12}$ oil-immersion objective should be available, but should be kept in the teacher's private cupboard).

Hand and pocket lenses.

Thermostat.

Klinostat.

Potometer.

Osmosis and absorption apparatus, including manometers.

Respirometer.

Recording transpirometer.

Photosynthometer.

Auxograph.

(Speaking generally, measurement experiments will be confined to the Sixth Form; for forms below, much of the necessary apparatus should be improvised.)

ZOOLOGY:—

Dissecting dishes and instruments, one set for each pupil. (Enamel dishes 9 in. × 6 in. × 1½ in. are the best, with cork carpets held down by strips of lead.)

Some form of freezing microtome.

Vivaria.

Chemical apparatus and reagents for physiology.

For all forms of live material consult the nearest University Professor of Zoology. See also the advertisement columns of *Nature*.

HUMAN PHYSIOLOGY:—

A human skeleton is useful.

Anatomical models of the eye, ear, larynx, nose, and heart.

Some forms of apparatus to show why air enters and leaves the lungs.—A large bell-jar with a stretched sheet of thin rubber tied over the open end, and a cork through which pass two short glass tubes; to the lower end of one tube is tied an elastic bag which is thus suspended in the bell-jar; through the other tube, air is driven into the bell-jar.—There are various forms of such apparatus obtainable from the makers.

Pulse demonstration apparatus: a glass U-tube manometer for demonstrating fluid pressure is linked up with thoroughly flexible elastic tubing; an ordinary india-rubber enema makes a suitable pump. A simple lever resting on the tubing will illustrate the pulse.

A *larynx*, hardened in spirits, then dissected out, may be preserved as a permanent flexible specimen by immersion in strong glycerine.

A *dialyser* for simple experiments on diffusion.

Chemical thermometers.

Essentials for experiments on salivary, gastric, and pancreatic digestion. (A water-bath to be kept at 40° C., and reagents, viz. HCl, 0·2 per cent; strong HNO_3; AmHO; NaHO, 5 per cent; very dilute H_2SO_4; Millom's reagent; Fehling's solution; Na_2CO_3, 1 per cent. For gastric and pancreatic digestion, Benger's "liquor pepticus" and "liquor pancreaticus" provide the best supply of enzymes for the preparation of the digestive solutions.)

(Bulky physiological material may be preserved in a large vessel containing formalin solution.)

The Workshop

All science teachers should make themselves familiar with the commoner tools used by carpenters and metal-workers. Moderate skill in most of the operations may be acquired with very little practice. A science teacher should be able to devise and make apparatus for simple experiments, to modify appa-

ratus, and to effect simple repairs. He should be able to use the lathe and the few machines often found in the school workshop. If no machines are available, he should learn to use the bench drill (cramp and brace), the breast drill, and the stocks and dies.

The following tools, &c., should be supplied for laboratory-workshop use:

Drills, cold chisels, punches, files, a smith's vice, a ½-lb. hammer, a 1½-lb. hammer, pair of 9-in. shears, round pliers, flat-nose pliers, soldering iron, tinman's solder, zinc chloride, "fluxite", rosin. Emery cloth, Nos. 1, F, FF. Blue-black emery paper, No. 0. A small anvil.

Screws; terminals; insulated wire for coils; brass rod, strip, and sheet; copper sheet; zinc sheet. Get iron castings from the local foundry, and from the local blacksmith such wrought iron as may be necessary.

The commoner carpenters' tools, and a small supply of hard and soft woods.

Lacquers: colourless, pale gold, French gold.

Cements: water-glass and lime cement, water-glass and Portland cement, cement for iron.

Dips: bright dip for brass, matt or dead dip.

Silvering mirrors: rather too difficult for amateurs to do well.

Useful books are Shenstone's *Glass-blowing*, Threlfall's *Laboratory Arts*, Woollatt's *Laboratory Arts*.—Much knowledge may be picked up by making friends with a village blacksmith, tinsmith, carpenter, and plumber. A day's initiation will go a long way. In a large town this kind of help is more difficult to obtain.

CHAPTER XXXIX

Science Libraries

Such a multitude of books on science are now being published that it is exceedingly difficult to make a selection for the school library. Specialists in all departments of science are

writing, some who know how to write and some who do not. A writer may have a great name as a specialist in his own line, and yet when he attempts to write about his work he may fail to give a clear account of it. On the other hand, a writer possessing gifts of clear expression may write on a subject about which he knows very little; he may perhaps serve up a few tit-bits which will interest the multitude but which are useless for the serious consideration of people who wish to acquire exact and reasoned knowledge. How is the teacher to make a selection? He cannot read all the books published, even if he has access to a first-class library. Who is to guide him?

"The survival of the fittest" applies to books as well as to living things. After a few years, books of little or no value die a natural death, though unfortunately they are not always cremated. The specific value of the survivors becomes gradually known, and selection is comparatively easy. The real difficulty is with the new books. Every science teacher desires to spend to advantage the usually small amount of money allotted annually for the purchase of new science books, and there is always the danger of second-rate books being selected.

Good sound copies of older books can usually be obtained second-hand. London contains dozens of well-known second-hand bookshops; Oxford and Cambridge come next, and some of the big provincial towns, especially the university towns, are a good third. There is no difficulty in building up a science library of older books, at a reasonable cost.

But even experienced and well-read science teachers are glad to have the help of prepared lists of books for school science libraries, and, of such lists, the best is that compiled by the Joint Committee of the Science Masters' Association and the Association of Women Science Teachers, with supplements. These associations are, I believe, ever ready to give advice to inquirers, and all science teachers ought, by active membership, to support these exceedingly useful associations.

The best reviews of new science books are to be found in *Nature* and in the *School Science Review*.* The former has

always been noted for its weighty reviews on new standard works of science, both British and foreign, and though many of the books are beyond the range of the work attempted in schools, they are just what the science teacher requires for building up his own private science library and for keeping his knowledge fresh. The *School Science Review* gives reviews by well-known science teachers who not only know their own subjects but who know what they are talking about from the point of view of class-room practice. I do not think I have ever read in its pages a review with which I disagreed.

Nature also issues periodically a supplement giving a list of all recently published works in mathematics, science, and technology. With this in his hand, a science teacher visiting a science library like that, say, of Messrs. H. K. Lewis, can examine any particular new book at once. Sir Richard Gregory read a particularly useful paper on " Standards of Book Selection in Science and Technology " at Cambridge in September, 1927; it was reproduced in *Nature*, 8th October, 1927.

It is, unfortunately, true that the majority of science books suitable for school use are written down to examination requirements. In this country, writers do not care—do not dare—to ignore these requirements, or the books will not sell. Thus, apart from works of the popular type, books of a strikingly original and stimulating kind are comparatively rare.

To compile a list of " best books " is to ask for trouble. Opinions necessarily differ, and this is all to the good. It would be a matter for regret if school libraries ever became standardized. Experienced teachers should compile lists for themselves.

Do not forget foreign books. German books are usually sound though they are apt to be ponderous. French books are more lively, almost invariably interesting, with a freshness of presentation. Not all of the vast number of American books are equally good by any means, but not a few of them are really excellent; those issued by the University of Chicago Press ought to be known to all science teachers.

Sonnenschein's *The Best Books* is a particularly useful

reference volume, though each edition is soon out of date, unfortunately.

Keep an eye on the papers occasionally read at meetings of the learned societies and often reproduced in *Nature*; also on lectures of the historical review type that are sometimes given by well-known men of science.—Sir J. A. Ewing's lecture on *A Century of Inventions*, given before the Institute of Civil Engineers on 4th June, 1928, is a case in point.

Here is a short supplementary list of books, historical and other, for general reading, some for the school library, some for the teacher's private library.

1. *A Short History of Science*, Sedgwick and Tyler.
2. *Introduction to the History of Science*, W. Libby.
3. *Introduction to the History of Science*, G. Sarton (Vol. I ready).
4. *Geschichte der Naturwissenschaften*, Dannemann (the best).
5. *Babylonians and Assyrians*, A. H. Sayce.
6. *History of Anthropology*, A. C. Haddon.
7. *Historia Animalium*, Aristotle (trs. by D. W. Thompson).
8. *The Works of Archimedes*, T. L. Heath.
9. *History of the Inductive Sciences*, W. Whewell.
10. *History of European Thought in the 19th Century*, J. T. Merz.
11. *Discovery*, Sir Richard Gregory.
12. *Pioneers of Science*, Sir Oliver Lodge.
13. *Martyrs of Science*, Sir David Brewster.
14. *A Short History of Mathematics*, Ball.
15. *A History of Mathematics*, Cajori.
16. *History of Greek Mathematics*, Gow.
17. *Science of Mechanics*, Mach.
18. *Astronomy*, A. R. Hinks.
19. *Great Astronomers*, Ball.
20. *Story of the Heavens*, Ball.
21. *Problems of Cosmogony and Stellar Dynamics*, Jeans.
22. *Lectures on Some Recent Advances in Physical Science*, P. G. Tait.
23. *Recent Advances in Physical Science*, W. C. D. Whetham.
24. *The New Physics*, Haas.
25. *Problems of Modern Physics*, Lorentz.
26. *Lectures on Theoretical Physics*, Lorentz.
27. *Matter and Energy*, Soddy.
28. *Radio-active Substances and their Relations*, Rutherford.
29. *Atoms and Rays*, Lodge.

30. *Atomic Structures and Spectral Lines*, Sommerfeld.
31. *Alchemy and the Beginnings of Chemistry*, Muir.
32. *History of Chemistry*, Thorpe.
33. *Essays on Historical Chemistry*, Thorpe.
34. *Progress of Scientific Chemistry in our own time*, Tilden.
35. *A History of Chemical Theories and Laws*, Muir.
36. *Industrial and Manufacturing Chemistry*, Martin.
37. *Alembic Club Reprints.*
38. *The Gases of the Atmosphere*, Ramsay.
39. *A History of Botany*, J. R. Green.
40. *Lectures on the History of Physiology in the 17th and 18th Centuries*, Michael Foster.
41. *On the Movement of the Heart's Blood*, Harvey.
42. *History and Scope of Zoology*, Lankester.
43. *Darwinism*, A. R. Wallace.
44. *Evolution in the Light of Modern Knowledge*, Jeans and others.
45. *Darwin and Modern Science*, Seward and others.
46. *Principles of Geology*, Lyell.
47. *Founders of Geology*, Geikie.
48. *Palæontology*, Swinnerton.
49. *Grammar of Science*, K. Pearson.
50. *Introduction to Science*, Thomson.
51. *Method and Results*, T. H. Huxley.
52. *Science and Hypothesis*, Poincaré.
53. *Bacon's Philosophical Works*, Ellis and Spedding.
54. *Memoirs of Sir Isaac Newton*, Brewster.
55. *Isaac Newton*, Memorial Volume; ed. W. J. Greenstreet.
56. *John Dalton*, Roscoe.
57. *Humphry Davy*, Thorpe.
58. *Faraday as a Discoverer*, Tyndall.
59. *Michael Faraday*, S. P. Thompson.
60. *Life and Letters of Faraday*, Bruce Jones.
61. *Life and Letters of Charles Darwin*, Francis Darwin.
62. *Darwin and after Darwin*, G. J. Romanes.
63. *Lord Kelvin*, A. Grey.
64. *Life of Pasteur*, Vallery-Radot.
65. *Pasteur and after Pasteur*, Paget.

APPENDIX

QUESTIONNAIRES FOR PUPILS AND FOR TEACHERS

A QUESTIONNAIRE FOR BOYS LEAVING SCHOOL

It would be reasonable to expect boys on leaving school to give intelligent answers to the following questions, which are not of the usual examination type. It does not, of course, follow that the necessary information will have been formally imparted during the science lessons. The boys will presumably have read up a good deal of science in addition to what they have read for examinations.

1. How could you estimate the number of flaps made in a second by the wings of a flying blue-bottle?

2. Explain why the new moon is always seen in the west.

3. Why will a clean needle float if placed gently on the surface of water?

4. Why does an india-rubber ball bounce?

5. What is the use of tall chimneys?

6. Draw a diagram to show clearly the length of the shortest looking-glass you require in order that you may see the reflection of the whole length of your figure.

7. What is a mirage? Why is it such a common phenomenon in the Soudan?

8. Explain what there is wonderful in the fact that the body temperature of all human beings in normal health is the same (98·4°).

9. When we think of some portion of the earth devoid of all forms of animal life, why must we necessarily think of it as something absolutely dark and silent, despite a brilliantly shining sun or violent thunderstorm?

10. If you were taken to the North Pole, how could you satisfy yourself that you were really there? Would the setting of the compass be affected? Could you still travel N., S., E., and W.? If not, why not?

11. How is it that bees do not mix up pollen hopelessly as they pass from flower to flower?

12. The sudden flaring up of a particular star a few years ago seemed to point to a tremendous stellar catastrophe. Astronomers stated that the catastrophe must actually have taken place in the reign of Queen Elizabeth. On what grounds was such a statement made?

13. Describe the manufacture of artificial silk.

14. What do you know of the by-products of a gas-works? Are any of them valuable? Who made the discovery?

15. How are tram rails welded together? What is the nature of the stuff used and what is the chemical action? Why is the welding necessary, considering that railway-rails are not treated similarly?

16. Describe how the electric energy of a broadcasting station is transmitted to your receiving-set. Inasmuch as energy is radiated from the station, why have you to provide further energy for the working of your own valve set?

17. A canal crosses over a road 30 feet wide by means of a bridge. A barge 16 feet long and weighing 20 tons passes along the canal. When the barge is over mid-bridge, what is the extra weight, if any, carried by the bridge?

18. Explain exactly how the engine of a motor-car works.

19. We think of the shape of rain-drops as spherical. Is there any ground for this?

20. It is sometimes said that when a ship goes down the boilers " blow up ". Why is it extremely unlikely that this really happens? What gives rise to the idea that it does happen? What is the nature of an explosion?

A QUESTIONNAIRE ON GENERAL SCIENCE

For Young Science Teachers

It would also be reasonable to expect young science teachers, who are hoping to be promoted to the headship of a science department, to test their knowledge by such questions as the following:

1. How do you account for Faraday's extraordinary success as a physicist, seeing that he had no knowledge of mathematics?

2. Was the electron discovered or invented? (If you are uncertain, consult Professor Armstrong.)

3. Discuss the future possibility of the transmutation of gold from base metals.

4. Why are we quite certain that the common microscope will never be constructionally improved so far that we shall be able to see molecules and atoms?

5. How far into the sun has it been estimated we can see? What is the evidence on which the estimate is based?

6. A chisel is sharpened on a grindstone and then finished on an oilstone. There is a fundamental difference between the two processes. What is it?

7. Justify the following statement: "A square mile of the most fertile soil can support with the solar heat it annually consumes only a definite number of human beings, which no art or science can increase."

8. Describe your mental picture of a cyclone. Produce the evidence to show (1) the shape, (2) the movements, of the cyclonic mass of air as you have conceived it.

9. How does a colour-blind person's view of the spectrum differ from that of a person of normal vision?

10. What is the estimated age of the earth, as made by physicists and geologists, respectively? Do you attach more value to one estimate than to the other? If so, why?

11. If the velocity of rotation of the earth were 17 times as great as it is now, what would be the consequence? Does the number 17 agree with your conclusion? How do you make the calculation?

12. What are the advantages of the modern steel girder and steel roof truss over the ancient stone arch and vault? Compare the ancient and modern methods of getting rid of lateral pressure in the spanning of large buildings and enclosed spaces.

13. Do you consider that the estimates of stellar distances and electronic magnitudes correspond approximately with actual fact? What part of the available evidence is experimental and what part inferential? Is the latter evidence convincing?

14. Do you favour the emission hypothesis or the wave hypothesis of light? If the former, how do you explain interference? If the latter, how do you make the hypothesis square with the quantum hypothesis?

15. Do you consider that the formaldehyde found in green leaves is an intermediate product in the manufacture of sugar from CO_2 and OH_2, or a mere by-product resulting from the sugar disintegration? Why? What in your opinion is the source of the great amount of energy for converting CO_2 into sugar? Are you satisfied that light alone is sufficient to provide it all?

16. If you were given the option, either to be bitten by a mosquito or to be stung by a wasp, which would you choose? Compare the toxic effects of the two.

17. Did Sir Arthur Keith's British Association address on Evolution strengthen your belief in the Evolutionary hypothesis? In your opinion, is the hypothesis now established on such a firm basis that it has passed into the region of strong probability? Are there any seriously weak links in the chain between the protozoan and the mammal?

18. A compressed helical steel spring fits exactly into a cylindrical glass dish. Dilute H_2SO_4 is poured into the dish, and the steel is dissolved. What has become of the potential energy stored in the spring? Are you *sure*? What experiment can you devise to prove your statement? Is the experiment really practicable?

19. It is generally assumed that the flexion lines on the palm of the hand have been induced by use. But they appear on the fœtal hand, before the corresponding movements have begun. Do you infer from this that acquired characters may be inherited?

20. Discuss with your classical colleagues the relative values, from the point of view of an intellectual training for citizenship, of classics and science (ignore the question of knowledge). Has science the advantage over classics, in any one particular? Has classics over science? Set out the facts and arguments, and try to get your judgment accepted by the Common Room.

A QUESTIONNAIRE ON METHODS OF TEACHING

For Young Science Teachers

It would also be reasonable to expect the same young science teachers to answer questions of the following type:

1. Draft a working syllabus in Hydrostatics, with an historical bias, based on the work of Archimedes, Pascal, and Boyle.

2. Criticize the various makes of Boyle's Law apparatus in the market, from the point of view of demonstrating the law clearly and convincingly to young pupils.

3. You are asked to devise a switchboard for a new lecture-room. How would you rig it up in order that it might be of the maximum practical value to pupils receiving lessons in electricity? What instruments should it carry, and why?

4. In their book, *First Principles of Chemistry*, Messrs. Dootson and Berry say that the Laws of Multiple and Reciprocal Proportions

ha.. become obsolete. Criticize this statement, especially in regard to its bearing on the teaching of the theory of chemistry.

5. At what stage in the teaching of science do you think that rigorously logical reasoning should be insisted on?

6. Do you agree that the main principles of a subject of science are likely to be obscured if applications and illustrations are freely used? If so, what is your remedy?

7. What are "leading questions"? When is a science teacher justified in using them?

8. As far as you can judge from books you have read and from opinions you may have heard expressed, do you think that science teach[illegible]s better now than it was a generation ago? If so, give precise reas[illegible] the opinion you hold.

[illegible] Germans, who have given at least as much attention to me[illegible]f science teaching as other leading nations have, are anythi[illegible] great believers in laboratory instruction for boys at schools. Ar[illegible] German boys have at least as much knowledge, show at least as intelligence, and have at least as firm a grasp of principles, a[illegible]h boys. How does this fact affect your views concerning our [illegible]ethods of science teaching?

Give instances of "verification" experiments that may be of [illegible] What is your experience of boys "cooking" their experiments, [illegible]ch cases?

11. Are text-books in science necessary for forms below the Sixth? If so, precisely what part should such books play in the course of science taught? Should a boy give priority to what you teach him, or to what the book tells him? Why?

12. Read through Professor Armstrong's book, and note down all the teaching principles which he advocates. Discuss these principles with your non-science colleagues. Now write down the *pros* and *cons* of the heuristic method. What do you think of the method? Are you going to adopt it or to reject it? Why?

13. For a subject like "Evolution", no practical work is possible. How will you ensure that the work attempted calls forth from the pupils an adequate mental effort?

14. Writing to *Nature*, a distinguished chemist referred to a lecture on Electrons, given by Sir J. J. Thomson to the students at Girton College, Cambridge. He said: "Sir J. J. Thomson can thrill the young things at Girton with an account of the new shingled electron and its waved front." Apparently the distinguished chemist denies that University students reading for Honours in science should receive a lecture from a world-famed physicist on a subject in which all the world is interested. What is your opinion of *his* opinion?

15. If there is one thing likely to shake the confidence of pupils

in their science teacher, it is his failure to make his experiments successful. But even in the hands of expert botanists, plant physiology experiments are apt to fail, particularly experiments on water-cultures. Repeated failures may induce the pupils to think either that the teacher does not know his work or that the experimental work is without value. Can you devise a scheme of apologetics to meet the case?

16. Draw up a working syllabus in chemistry for the four years preceding the School Certificate examination, showing clearly when you would begin to teach the theory of the subject, how you would develop it step by step, and where and when.

17. In a country school where very few pupils remai[illegible] the school certificate stage, what steps would you take to ens[illegible] n adequate course of elementary biology is included in t[illegible] ace course?

18. What course of reading would you advise for a Si[illegible] m, to make the boys keen to examine the foundations of an[illegible] ce subject in which they are interested?

19. Some years ago a science teacher, working single-[illegible] l, was trying to extinguish the burning woodwork (pitch-pin[illegible] fume cupboard which had been set on fire by a badly plac[illegible] draught flame, when he was urgently called to a boy who had b[illegible] unconscious through the inhalation of chlorine. How would you [illegible] coped with the double emergency?

20. If you were Head of the science department in a large school, how would you organize the work necessary for the proper correction of the many hundreds of notebooks in use? What advice on the subject would you give to your colleagues?

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